State of California
The Resources Agency
Department of Water Resources

FINAL REPORT
EVALUATION OF FLOW FLUCTUATION EFFECTS ON CHINOOK SALMON REDD DEWATERING IN THE LOWER FEATHER RIVER
SP-F10, Task 2D

Oroville Facilities Relicensing
FERC Project No. 2100

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ARNOLD SCHWARZENEGGER
Governor
State of California

MIKE CHRISMAN
Secretary for Resources
The Resources Agency

LESTER A. SNOW
Director
Department of Water Resources

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This report was prepared under the direction of

Terry J. Mills .... Environmental Program Manager I, DWR

by

Paul Bratovich ....Principal/Fisheries Technical Lead, SWRI
David Olson................................ Senior Environmental Scientist/Project Manager, SWRI
Jose A. Perez-Comas ....Senior Environmental Scientist/Author, SWRI
Salvador Becerra-Muñoz.......................Associate Environmental Scientist/Author, SWRI
Amanda O'Connell .... Environmental Planner/Author, SWRI
Adrian Pitts..Associate Environmental Scientist/Author, SWRI

REPORT SUMMARY

The purpose of SP-F10 Task 2D is to evaluate the potential for, and the impact from, Chinook salmon redd dewatering due to flow fluctuations in the lower Feather River. Operations of the Oroville Facilities affect instream flows and corresponding water surface elevations in the lower Feather River which, in turn, influence the potential for redd dewatering. The results of this study provide information regarding the percentage of Chinook salmon redds potentially dewatered under current operations. Additionally, the results of this study could be used to evaluate future potential Resource Actions involving flow changes and their potential effects on redd dewatering.

The incidence of apparent redd dewatering events in the lower Feather River during the 2002/2003 and 2003/2004 spawning and egg incubation periods was compared with the estimated total number of Chinook salmon redds constructed during the 2002 and 2003 spawning seasons, respectively. In the lower Feather River, most Chinook salmon reportedly spawn in the low flow channel (LFC) (Sommer et al. 2001). In 2002, an estimated 23,564 (63.6 percent of the total) Chinook salmon redds were constructed in the LFC, whereas an estimated 13,490 (36.4 percent of the total) Chinook salmon redds were constructed in the high flow channel (HFC). In 2003, an estimated 21,088 (57.4 percent of the total) Chinook salmon redds were constructed in the LFC, while an estimated 15,624 (42.6 percent of the total) Chinook salmon redds were constructed in the HFC.

Project operations apparently do not result in Chinook salmon redd dewatering in the LFC, within which an estimated 63.6 and 57.4 percent, respectively, of all lower Feather River Chinook salmon redds were constructed in 2002 and 2003, due to the relatively constant flows (approximately 600 cfs) that occur during the spawning and incubation periods.

In the HFC, an estimated average of 3.1 percent of all Chinook salmon redds was subjected to dewatering during the 2002/2003 spawning and incubation period, whereas an estimated average of 0.4 percent was subjected to dewatering during 2003/2004.

For the LFC and HFC combined, an estimated average of 1.1 and 0.2 percent of all Chinook salmon redds would have been subjected to dewatering during the 2002/2003 and 2003/2004 spawning and incubation periods, respectively.

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1.0 INTRODUCTION

Flow fluctuations are characterized as either rapid changes in streamflow that occur over relatively short periods (minutes, hours or days), or changes from base conditions sustained during a season. Flow fluctuations in the lower Feather River can occur under flood control releases, scheduled maintenance operations, storm events, facility failures, or emergency shutdowns, and may subject salmonid redds to dewatering. Redd dewatering occurs when water levels fall below the level of egg deposition. Redd dewatering may lead to egg and alevin mortality (Becker et al. 1982; Becker et al. 1983; Reiser and Whitney 1983). Chinook salmon initial year class production may be affected if a relatively high proportion of redds are dewatered during the spawning season.

1.1 BACKGROUND INFORMATION

Ongoing operation of the Oroville Facilities has the potential to dewater Chinook salmon redds in the lower Feather River resulting from changes in flow and corresponding changes in river stage. As a component of study plan (SP)-F10, *Evaluation of Project Effects on Salmonids and their Habitat in the Feather River Below the Fish Barrier Dam,* Task 2 of SP-10 evaluates project effects on the spawning and incubation period of salmonids in the lower Feather River. Task 2D, herein, evaluates the effects of flow fluctuations on Chinook salmon redd dewatering.

1.1.1 Statutory/Regulatory Requirements

The purpose of SP-F10 Task 2D is to evaluate the potential for, and the impact from, the dewatering of Chinook salmon redds due to flow fluctuations in the lower Feather River. Salmonids present in the lower Feather River include spring-run Chinook salmon (*Oncorhynchus tshawytscha*), fall-run Chinook salmon (*O. tshawytscha*), and steelhead (*O. mykiss*). On September 16, 1999, naturally-spawned Central Valley spring-run Chinook salmon were listed as threatened under the federal Endangered Species Act (ESA) by the Department of Commerce, National Oceanic and Atmospheric Administration, National Marine Fisheries Service (NOAA Fisheries) (NOAA Fisheries 1999). The Central Valley spring-run Chinook salmon Evolutionarily Significant Unit (ESU) includes all naturally-spawned populations of spring-run Chinook salmon in the Sacramento River and its tributaries, which includes naturally-spawned spring-run Chinook salmon in the lower Feather River (NOAA Fisheries 1999). On March 19, 1998, naturally-spawned Central Valley steelhead were listed as threatened under the federal ESA by NOAA Fisheries (NOAA Fisheries 1998). The Central Valley steelhead ESU includes all naturally-spawned populations of steelhead in the Sacramento and San Joaquin rivers and their tributaries, which includes naturally-spawned steelhead in the lower Feather River (NOAA Fisheries 1998).

The results and recommendations from this study fulfill, in part, statutory and regulatory requirements mandated by the ESA as it pertains to Central Valley spring-run and fall-run Chinook salmon. In addition to the ESA and California Species of Special Concern, Section 4.51(f)(3) of 18 CFR requires reporting of certain types of information in the Federal Energy Regulatory Commission (FERC) application for license of major hydropower projects, including a discussion of the fish, wildlife, and botanical resources in the vicinity of the project (FERC 2001). The discussion is required to identify the potential impacts of the project on these resources, including a description of any anticipated continuing impact for on-going and future operations. As a subtask of SP-F10, Task 2D fulfills a portion of the FERC application requirements by detailing the potential effects of flow fluctuations on Chinook salmon redd dewatering. In addition to fulfilling these requirements, information collected during this task may be used in developing or evaluating potential Resource Actions.

1.1.2 Study Area

The study area for Task 2D of SP-F10 extends from the Fish Barrier Dam downstream to Honcut Creek, which represents the Chinook salmon spawning area in the lower Feather River. The study area in which the modeling results of Task 2D of SP-F10 specifically apply to the lower Feather River extends from the Thermalito Afterbay Outlet at river mile (RM) 59 downstream to the confluence with Honcut Creek.

1.1.2.1 Description

Flow requirements for the lower Feather River were determined by the August 26, 1983 agreement between the Department of Water Resources (DWR) and California Department of Fish and Game (DFG) titled "*Agreement Concerning the Operation of the Oroville Division of State Water Project for Management of Fish & Wildlife.*" This agreement states that a flow of 600 cfs is to be released into the main channel of the lower Feather River from the Thermalito Diversion Dam (i.e. diversion dam outlet, diversion dam power plant, and the Feather River Fish Hatchery pipeline) for fishery purposes. In the reach of the lower Feather River downstream of the Thermalito Afterbay Outlet, water flow is supplemented by releases from the Thermalito Afterbay Outlet to maintain a minimum flow downstream to the mouth of the Feather River. During the month of September, the flow requirement in the reach of the lower Feather River extending downstream from the Thermalito Afterbay Outlet is 1,000 cfs. During the months of October through February, the minimum flow requirements for this reach are 1,200 or 1,700 cfs, depending on the percentage of unimpaired runoff of the Feather River near Oroville from the preceding water year as compared to the normal unimpaired runoff of 1,942,000 acre-feet (mean of 1911-1960). Additionally, there is a requirement that specifies that if the highest average one hour flow of the combined project releases exceeds 2,500 cfs between October 15 and November 30, with the exception of releases for flood control, accidents, project failure, and major or unusual maintenance, then the minimum flow from October through March shall not be less than

500 cfs of the highest average one hour flow. The 2,500 cfs threshold was envisioned to protect redds in the event that spawning occurs in the overbank areas. From October through February, if flow is 1,700 cfs, then flow must remain at 1,700 cfs through March, and if flow is 1,200 cfs, then the flow requirement is 1,000 cfs in March. The project is usually operated such that only one major reduction in flow occurs downstream of Thermalito Afterbay Outlet during the months in which Chinook salmon redds may be present in the lower Feather River (generally just before October 15).

1.2 DESCRIPTION OF FACILITIES

The Oroville Facilities were developed as part of the State Water Project (SWP), a water storage and delivery system of reservoirs, aqueducts, power plants, and pumping plants. The main purpose of the SWP is to store and distribute water to supplement the needs of urban and agricultural water users in northern California, the San Francisco Bay area, the San Joaquin Valley, and southern California. The Oroville Facilities are also operated for flood management, power generation, to improve water quality in the Delta, provide recreation, and enhance fish and wildlife.

FERC Project No. 2100 encompasses 41,100 acres and includes Oroville Dam and Reservoir, three power plants (Hyatt Pumping-Generating Plant, Thermalito Diversion Dam Power Plant, and Thermalito Pumping-Generating Plant), Thermalito Diversion Dam, the Feather River Fish Hatchery and Fish Barrier Dam, Thermalito Power Canal, Oroville Wildlife Area (OWA), Thermalito Forebay and Forebay Dam, Thermalito Afterbay and Afterbay Dam, and transmission lines, as well as a number of recreational facilities. An overview of these facilities is provided on Figure 1.2-1. The Oroville Dam, along with two small saddle dams, impounds Lake Oroville, a 3.5-million-acre-feet (MAF) capacity storage reservoir with a surface area of 15,810 acres at its normal maximum operating level.

The hydroelectric facilities have a combined licensed generating capacity of approximately 762 megawatts (MW). The Hyatt Pumping-Generating Plant is the largest of the three power plants with a capacity of 645 MW. Water from the six-unit underground power plant (three conventional generating and three pumping-generating units) is discharged through two tunnels into the Feather River just downstream of Oroville Dam. The plant has a generating and pumping flow capacity of 16,950 cfs and 5,610 cfs, respectively. Other generation facilities include the 3-MW Thermalito Diversion Dam Power Plant and the 114-MW Thermalito Pumping-Generating Plant.

Thermalito Diversion Dam, four miles downstream of the Oroville Dam creates a tail water pool for the Hyatt Pumping-Generating Plant and is used to divert water to the Thermalito Power Canal. The Thermalito Diversion Dam Power Plant is a 3-MW power plant located on the left abutment of the Diversion Dam. The power plant releases a maximum of 615 cubic feet per second (cfs) of water into the river.

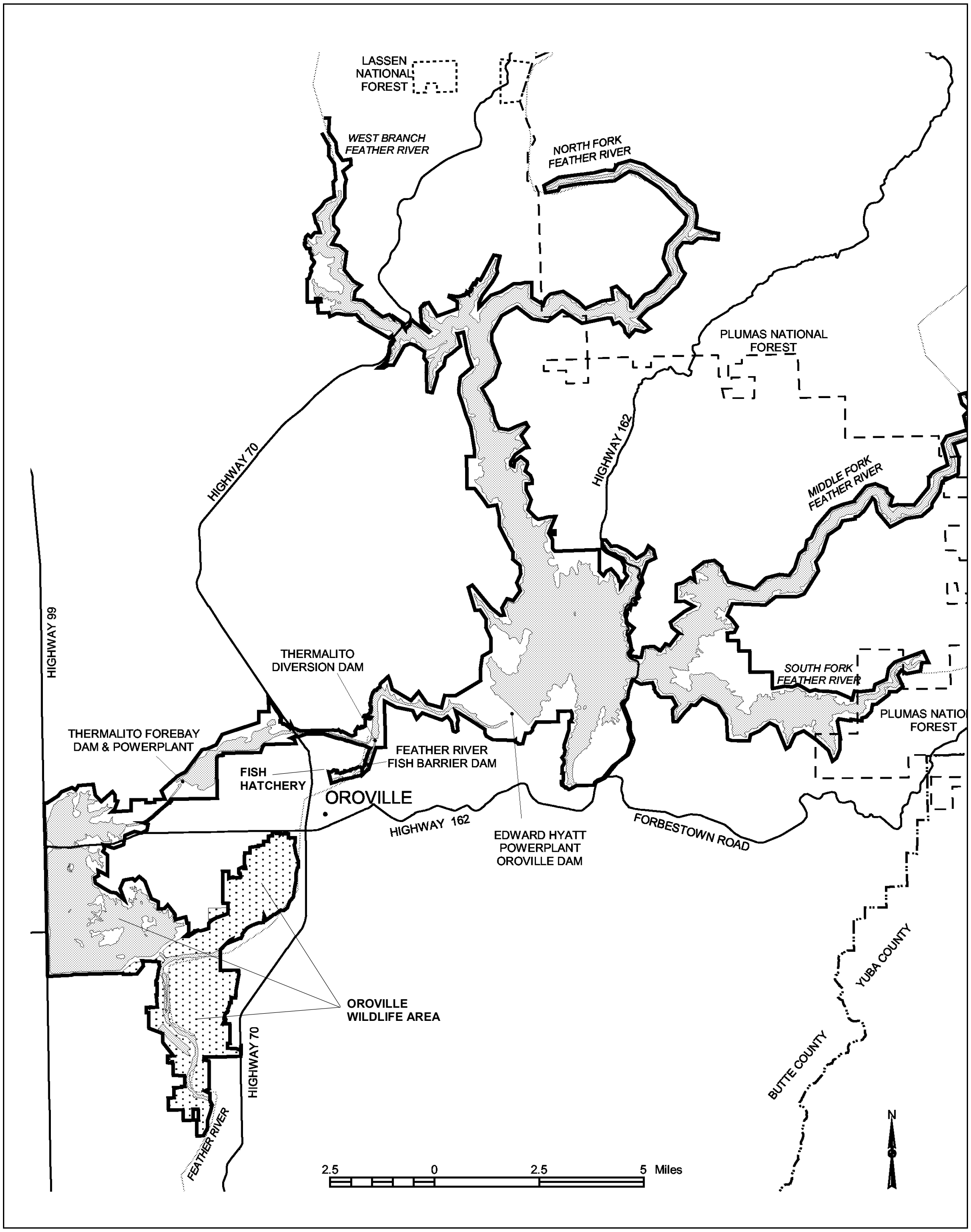

Figure 1.2-1. Oroville Facilities FERC Project Boundary.

The Power Canal is a 10,000-foot-long channel designed to convey generating flows of 16,900 cfs to the Thermalito Forebay and pump-back flows to the Hyatt Pumping-

Generating Plant. The Thermalito Forebay is an off-stream regulating reservoir for the 114-MW Thermalito Pumping-Generating Plant. The Thermalito Pumping-Generating Plant is designed to operate in tandem with the Hyatt Pumping-Generating Plant and has generating and pump-back flow capacities of 17,400 cfs and 9,120 cfs, respectively. When in generating mode, the Thermalito Pumping-Generating Plant discharges into the Thermalito Afterbay, which is contained by a 42,000-foot-long earth-fill dam. The Afterbay is used to release water into the Feather River downstream of the Oroville Facilities, helps regulate the power system, provides storage for pump-back operations, and provides recreational opportunities. Several local irrigation districts receive water from the Afterbay.

The Feather River Fish Barrier Dam is downstream of the Thermalito Diversion Dam and immediately upstream of the Feather River Fish Hatchery. The flow over the dam maintains fish habitat in the low-flow channel of the Feather River between the dam and the Afterbay outlet, and provides attraction flow for the hatchery. The hatchery was intended to compensate for spawning grounds lost to returning salmon and steelhead trout from the construction of Oroville Dam. The hatchery can accommodate an average of 15,000 to 20,000 adult fish annually.

The Oroville Facilities support a wide variety of recreational opportunities. They include: boating (several types), fishing (several types), fully developed and primitive camping (including boat-in and floating sites), picnicking, swimming, horseback riding, hiking, off-road bicycle riding, wildlife watching, hunting, and visitor information sites with cultural and informational displays about the developed facilities and the natural environment. There are major recreation facilities at Loafer Creek, Bidwell Canyon, the Spillway, North and South Thermalito Forebay, and Lime Saddle. Lake Oroville has two full-service marinas, five car-top boat launch ramps, ten floating campsites, and seven dispersed floating toilets. There are also recreation facilities at the Visitor Center and the OWA.

The OWA comprises approximately 11,000-acres west of Oroville that is managed for wildlife habitat and recreational activities. It includes the Thermalito Afterbay and surrounding lands (approximately 6,000 acres) along with 5,000 acres adjoining the Feather River. The 5,000 acre area straddles 12 miles of the Feather River, which includes willow and cottonwood lined ponds, islands, and channels. Recreation areas include dispersed recreation (hunting, fishing, and bird watching), plus recreation at developed sites, including Monument Hill day use area, model airplane grounds, three boat launches on the Afterbay and two on the river, and two primitive camping areas. California Department of Fish and Game's (DFG) habitat enhancement program includes a wood duck nest-box program and dry land farming for nesting cover and improved wildlife forage. Limited gravel extraction also occurs in a number of locations.

1.3 CURRENT OPERATIONAL CONSTRAINTS

Operation of the Oroville Facilities varies seasonally, weekly and hourly, depending on hydrology and the objectives DWR is trying to meet. Typically, releases to the Feather River are managed to conserve water while meeting a variety of water delivery requirements, including flow, temperature, fisheries, recreation, diversion and water quality. Lake Oroville stores winter and spring runoff for release to the Feather River as necessary for project purposes. Meeting the water supply objectives of the SWP has always been the primary consideration for determining Oroville Facilities operation (within the regulatory constraints specified for flood control, in-stream fisheries, and downstream uses). Power production is scheduled within the boundaries specified by the water operations criteria noted above. Annual operations planning is conducted for multi-year carry over. The current methodology is to retain half of the Lake Oroville storage above a specific level for subsequent years. Currently, that level has been established at 1,000,000 acre-feet (af); however, this does not limit draw down of the reservoir below that level. If hydrology is drier than expected or requirements greater than expected, additional water would be released from Lake Oroville. The operations plan is updated regularly to reflect changes in hydrology and downstream operations. Typically, Lake Oroville is filled to its maximum annual level of up to 900 feet above mean sea level (msl) in June and then can be lowered as necessary to meet downstream requirements, to its minimum level in December or January. During drier years, the lake may be drawn down more and may not fill to the desired levels the following spring. Project operations are directly constrained by downstream operational constraints and flood management criteria as described below.

1.3.1 Downstream Operation

An August 1983 agreement between DWR and DFG entitled, “Agreement Concerning the Operation of the Oroville Division of the State Water Project for Management of Fish & Wildlife,” sets criteria and objectives for flow and temperatures in the low flow channel and the reach of the Feather River between Thermalito Afterbay and Verona. This agreement: (1) establishes minimum flows between Thermalito Afterbay Outlet and Verona which vary by water year type; (2) requires flow changes under 2,500 cfs to be reduced by no more than 200 cfs during any 24-hour period, except for flood management, failures, etc.; (3) requires flow stability during the peak of the fall-run Chinook spawning season; and (4) sets an objective of suitable temperature conditions during the fall months for salmon and during the later spring/summer for shad and striped bass.

1.3.1.1 Instream Flow Requirements

The Oroville Facilities are operated to meet minimum flows in the Lower Feather River as established by the 1983 agreement (see above). The agreement specifies that Oroville Facilities release a minimum of 600 cfs into the Feather River from the

Thermalito Diversion Dam for fisheries purposes. This is the total volume of flows from the diversion dam outlet, diversion dam power plant, and the Feather River Fish Hatchery pipeline.

Generally, the instream flow requirements below Thermalito Afterbay are 1,700 cfs from October through March, and 1,000 cfs from April through September. However, if runoff for the previous April through July period is less than 1,942,000 af (i.e., the 1911-1960 mean unimpaired runoff near Oroville), the minimum flow can be reduced to 1,200 cfs from October to February, and 1,000 cfs for March. A maximum flow of 2,500 cfs is maintained from October 15 through November 30 to prevent spawning in overbank areas that might become de-watered.

1.3.1.2 Water Temperature Requirements

The Diversion Pool provides the water supply for the Feather River Fish Hatchery. The hatchery objectives are 52°F for September, 51°F for October and November, 55°F for December through March, 51°F for April through May 15, 55°F for last half of May, 56°F for June 1-15, 60°F for June 16 through August 15, and 58°F for August 16-31. A temperature range of plus or minus 4°F is allowed for objectives, April through November.

There are several temperature objectives for the Feather River downstream of the Afterbay Outlet. During the fall months, after September 15, the temperatures must be suitable for fall-run Chinook. From May through August, they must be suitable for shad, striped bass, and other warmwater fish.

The National Marine Fisheries Service has also established an explicit criterion for steelhead trout and spring-run Chinook salmon. Memorialized in a biological opinion on the effects of the Central Valley Project and SWP on Central Valley spring-run Chinook and steelhead as a reasonable and prudent measure; DWR is required to control water temperature at Feather River mile 61.6 (Robinson's Riffle in the low-flow channel) from June 1 through September 30. This measure requires water temperatures less than or equal to 65°F on a daily average. The requirement is not intended to preclude pump-back operations at the Oroville Facilities needed to assist the State of California with supplying energy during periods when the California ISO anticipates a Stage 2 or higher alert.

The hatchery and river water temperature objectives sometimes conflict with temperatures desired by agricultural diverters. Under existing agreements, DWR provides water for the Feather River Service Area (FRSA) contractors. The contractors claim a need for warmer water during spring and summer for rice germination and growth (i.e., 65°F from approximately April through mid May, and 59°F during the remainder of the growing season). There is no obligation for DWR to meet the rice water temperature goals. However, to the extent practical, DWR does use its operational flexibility to accommodate the FRSA contractor's temperature goals.

1.3.1.3 Water Diversions

Monthly irrigation diversions of up to 190,000 (July 2002) af are made from the Thermalito Complex during the May through August irrigation season. Total annual entitlement of the Butte and Sutter County agricultural users is approximately 1 maf. After meeting these local demands, flows into the lower Feather River continue into the Sacramento River and into the Sacramento-San Joaquin Delta. In the northwestern portion of the Delta, water is pumped into the North Bay Aqueduct. In the south Delta, water is diverted into Clifton Court Forebay where the water is stored until it is pumped into the California Aqueduct.

1.3.1.4 Water Quality

Flows through the Delta are maintained to meet Bay-Delta water quality standards arising from DWR's water rights permits. These standards are designed to meet several water quality objectives such as salinity, Delta outflow, river flows, and export limits. The purpose of these objectives is to attain the highest water quality, which is reasonable, considering all demands being made on the Bay-Delta waters. In particular, they protect a wide range of fish and wildlife including Chinook salmon, Delta smelt, striped bass, and the habitat of estuarine-dependent species.

1.3.2 Flood Management

The Oroville Facilities are an integral component of the flood management system for the Sacramento Valley. During the wintertime, the Oroville Facilities are operated under flood control requirements specified by the U.S. Army Corps of Engineers (USACE). Under these requirements, Lake Oroville is operated to maintain up to 750,000 af of storage space to allow for the capture of significant inflows. Flood control releases are based on the release schedule in the flood control diagram or the emergency spillway release diagram prepared by the USACE, whichever requires the greater release. Decisions regarding such releases are made in consultation with the USACE.

The flood control requirements are designed for multiple use of reservoir space. During times when flood management space is not required to accomplish flood management objectives, the reservoir space can be used for storing water. From October through March, the maximum allowable storage limit (point at which specific flood release would have to be made) varies from about 2.8 to 3.2 maf to ensure adequate space in Lake Oroville to handle flood flows. The actual encroachment demarcation is based on a wetness index, computed from accumulated basin precipitation. This allows higher levels in the reservoir when the prevailing hydrology is dry while maintaining adequate flood protection. When the wetness index is high in the basin (i.e., wetness in the watershed above Lake Oroville), the flood management space required is at its greatest amount to provide the necessary flood protection. From April through June, the maximum allowable storage limit is increased as the flooding potential decreases, which allows capture of the higher spring flows for use later in the year. During September, the maximum allowable storage decreases again to prepare for the next flood season. During flood events, actual storage may encroach into the flood reservation zone to prevent or minimize downstream flooding along the Feather River.

2.0 NEED FOR STUDY

Task 2D is a subtask of SP-F10, *Evaluation of Project Effects on Salmonids and their Habitat in the Feather River below the Fish Barrier Dam*. Task 2D fulfills a portion of the FERC application requirements by evaluating the potential for, and the impact from, the dewatering of Chinook salmon redds due to flow fluctuations in the lower Feather River. In addition to fulfilling statutory requirements, information collected during this task may be used in developing or evaluating potential Resource Actions.

This study is necessary, in part, because operations of the Oroville Facilities affect instream flow and corresponding water surface elevation, with the potential to dewater redds in the lower Feather River. Additionally, performing this study is necessary because the study results yield a modeling tool that could be used to evaluate various flow regimes and the associated potential for salmonid redd dewatering.

SP-F10 is titled *Evaluation of Project Effects on Salmonids and their Habitat in the Feather River below the Fish Barrier Dam*. Task 2D, herein, evaluates the potential effects of flow fluctuations on Chinook salmon redd dewatering. Task 2A evaluates spawning and incubation substrate availability and suitability, Task 2B evaluates the effects of the timing, magnitude and frequency of flows on spawning distributions, and Task 2C evaluates the timing, magnitude and frequency of water temperatures and their effects on the distribution of spawning salmonids, and egg and alevin survival. For further description of Tasks 2A, 2B and 2C, see SP-F10 and associated interim and final reports.

3.0 STUDY OBJECTIVE

The objective of SP-F10 Task 2D is to evaluate the potential for, and the impact from, the dewatering of Chinook salmon redds due to flow fluctuations in the lower Feather River.

3.1 APPLICATION OF STUDY INFORMATION

The purpose of SP-F10 Task 2D is to evaluate the effects of flow fluctuations on Chinook salmon redd dewatering in the lower Feather River. Information obtained in this study is associated with, and will be applied to, the following purposes and activities.

3.1.1 Department of Water Resources/Stakeholders

The information from this analysis will be used by DWR and the Environmental Work Group (EWG) to evaluate potential on-going effects of project operations by evaluating the incidence of Chinook salmon redd dewatering in the lower Feather River in 2002. Additionally, data collected in this task serves as a foundation for future evaluation and development of potential Resource Actions.

3.1.2 Other Studies

As a subtask of study plan SP-F10, *Evaluation of Project Effects on Salmonids and their Habitat in the Feather River below the Fish Barrier Dam,* Task 2 of SP-F10 evaluates project effects on the spawning and incubation period of salmonids in the lower Feather River. Task 2D, herein, evaluates the potential for, and the impact from, dewatering of Chinook salmon redds resulting from flow fluctuations in the lower Feather River. Task 2A evaluates spawning and incubation substrate availability and suitability, Task 2B evaluates the effects of the timing, magnitude and frequency of flows on spawning distributions, and Task 2C evaluates the timing, magnitude and frequency of water temperatures and their effects on the distribution of spawning salmonids, and egg and alevin survival. For further description of Tasks 2A, 2B, or 2C, see SP-F10 and associated interim and final reports.

3.1.3 Environmental Documentation

In addition to Section 4.51(f)(3) of 18 CFR, which requires reporting of certain types of information in the Federal Energy Regulatory Commission (FERC) application for license of major hydropower projects (FERC 2001), it may be necessary to satisfy the requirements of the National Environmental Policy Act (NEPA) as well as the Endangered Species Act (ESA). Because FERC has the authority to grant an operating license to DWR for continued operation of the Oroville Facilities, discussion is required to identify the potential impacts of the project on many types of resources, including fish, wildlife, and botanical resources. In addition, NEPA requires discussion of any anticipated continuing impact from on-going and future operations. To satisfy NEPA and ESA, DWR is preparing a Preliminary Draft Environmental Assessment (PDEA) to attach to the FERC license application, which shall include information provided by this study plan report.

3.1.4 Settlement Agreement

In addition to statutory and regulatory requirements, SP-F10 Task 2D provides information which may be useful in the development of potential Resource Actions to be negotiated during the collaborative process. Additionally, information obtained from analysis of the potential for Chinook salmon redd dewatering due to flow fluctuations in the lower Feather River could be used to identify operating procedures negotiated during the collaborative settlement process.

4.0 METHODOLOGY

4.1 STUDY DESIGN

Evaluation of the potential effects of flow fluctuations on spawning salmonids typically involves calculating flow (river stage) reduction between consecutive days in spawning areas during the spawning and incubation season, and expressing the number of stage reductions of a given magnitude that occurred during the spawning and incubation period. Interpretations of results using this approach are limited because information concerning the percentage of the spawning population potentially affected by stage reductions occurring during the spawning and incubation season may not be incorporated. In general, most redds are constructed during identifiable peaks of Chinook salmon spawning activity, with variable overall temporal distribution.

In this report, an approach is presented that assesses the potential effects of flow fluctuations on Chinook salmon redd dewatering which incorporates information on the temporal distribution of spawning activity, redd depth distribution, duration of embryo incubation through fry emergence, and maximum reduction in river stage throughout the incubation period.

4.1.1 Conceptual Approach

The assessment approach estimates the percentage of Chinook salmon redds potentially affected by river stage reductions from the date of redd construction through the end of the corresponding incubation period. The assessment approach is data intensive. In addition to daily flows and river stages within the spawning grounds from the date of redd construction through the end of the corresponding incubation period, the approach requires information regarding:

- The distribution of spawning activity, expressed as the daily percent of newly built redds relative to the total number of redds built throughout the spawning season;
- The duration of the incubation period, expressed as days from fertilization of eggs (defined as date of redd construction) through fry emergence, as a function of water temperature; and
- Redd depth distributions.

4.2 HOW AND WHERE THE STUDIES WERE CONDUCTED

4.2.1 2002/2003 Modeling Approach

The modeling approach to evaluate the potential for Chinook salmon redd dewatering in the lower Feather River required the following data:

1) Individual-day Chinook salmon carcass counts in the LFC and HFC from the carcass survey which extended from September 3 through December 19, 2002 (DWR Unpublished Work);
2) The number of male and female carcasses identified in the LFC and HFC during the 2002 carcass survey (DWR Unpublished Work);
3) The number of female carcasses categorized as "spawned" or "unspawned" in the LFC and HFC during the 2002 carcass survey (DWR Unpublished Work);
4) Depth distribution of Chinook salmon redds in the HFC (DWR Unpublished Work);
5) Mean daily flow below the Thermalito Afterbay (CDEC) and corresponding river stage (TRPA, unpublished data) from August 13, 2002 through February 24, 2003; and
6) Average mean daily water temperatures from six data loggers distributed throughout the HFC from August 13, 2002 through February 24, 2003.

Most of the data required some processing prior to their use in the estimation of potential flow fluctuation effects on Chinook salmon redd dewatering. The evaluation of lower Feather River flow fluctuation effects on Chinook salmon redd dewatering was a multi-step process that required three major assumptions:

1) Chinook salmon incubation through emergence requires 1550 °F accumulated thermal units (ATU);
2) Observed redd depth distribution is representative of true redd depth distribution; and
3) Carcass survey data can be utilized as an appropriate surrogate for the temporal distribution of spawning activity.

4.2.2 2003/2004 Modeling Approach

2003 carcass survey data were collected following the same sampling protocols as those utilized to obtain data in 2002. The modeling approaches for both sets of data also were the same. The following data were needed for the modeling approach in 2003:

1) Individual-day Chinook salmon carcass counts in LFC and HFC from the 2003 carcass survey, conducted September 2, 2003 through December 17, 2003 (DWR Unpublished Work);
2) The number of male and female carcasses identified in the 2003 carcass survey for both the LFC and the HFC (DWR Unpublished Work);
3) The number of female carcasses categorized as “spawned” and “unspawned” in the LFC and the HFC during the 2003 survey (DWR Unpublished Work);
4) Depth distribution of Chinook salmon redds in the HFC during 2003 (DWR Unpublished Work);

5) Mean daily flow below the Thermalito Afterbay (CDEC) and corresponding river stage (TRPA, unpublished data) from August 9, 2004 through March 13, 2004; and
6) Average mean daily water temperatures from six data loggers distributed throughout the HFC from August 9, 2004 through March 13, 2004.

In addition, the same data conditioning and major assumptions, described below, apply to both the 2002/2003 and 2003/2004 spawning and incubation seasons analyzed in this report.

4.2.3 Chinook salmon embryo incubation duration

Daily changes in river stage have the potential to result in Chinook salmon redd dewatering throughout the embryo incubation period, inducing egg and pre-emergent alevin mortality. The current assessment of flow fluctuation effects on Chinook salmon redd dewatering in the lower Feather River requires estimation of the number of incubation days (from egg fertilization through fry emergence) for any redd built at any time during the spawning season.

Establishing a method of determining the duration of Chinook salmon embryo incubation is necessary because eggs and alevins are susceptible to dewatering caused by flow reductions. The duration of the incubation period is primarily dependent on water temperature; specifically, on an accumulation of a required number of thermal units.

The time required for salmonid egg incubation varies with average stream temperature (Raleigh et al. 1986). The duration of Chinook salmon embryo incubation reportedly ranges from 40 to 60 days when water temperatures range from 41 ºF to 55.4 ºF (5 ºC - 13 ºC) (Bjornn and Reiser 1991; Moyle 2002). The accumulation of a given number of thermal units (ATU) determines embryonic developmental rate and fry emergence timing. An accumulated thermal unit can be defined as each degree Celsius above zero (Raleigh et al. 1986), or as degrees Fahrenheit above freezing, accumulated during a 24-hour period (DFG 1998) (e.g., 1000 °C ATU = 50 days at 20 °C or 100 days at 10 °C; 1000 °F ATU = 50 days at 52 °F or 100 days at 42 °F).

Chinook salmon incubation periods have been reported in terms of ATUs required until hatching or emergence, rather than an average or estimated number of days required for incubation (DFG 1998; McCullough 1999; Raleigh et al. 1986). The reported ranges of required ATUs to hatching or emergence for Chinook salmon differ among authors. These discrepancies could be due to differences in water temperature requirements based on genetic differences between populations or other factors. Water temperature tolerances for adult Chinook salmon have been reported to differ by approximately one degree Fahrenheit for each degree difference in latitude (Bell 1991). It is uncertain if similar differences exist for the thermal requirements of egg incubation through fry emergence. The number of ATUs required through egg hatching has been reported to range from 900 to 1,000 Celsius thermal units (Raleigh et al. 1986). In two different forks of the John Day River, Oregon, 1,528 and 1,211 Celsius thermal units were required for Chinook salmon eggs to incubate, hatch, and fry to emerge (McCullough 1999).

Genetic variability among the many runs of Chinook salmon may explain the discrepancies observed in the ATUs required for emergence. These differences also may be accounted for by an apparent evolved compensation mechanism that slows Pacific salmon egg development at warmer water temperatures. More thermal units are required for development at higher temperatures to help ensure that abnormally high water temperatures do not result in earlier-than-normal fry emergence (Beacham and Murray 1990). Early emerging fry may experience higher mortality because river conditions are not yet suitable for rearing (McCullough 1999).

DFG states in "*A status review of spring-run Chinook salmon (Oncorhynchus tshawytscha) in the Sacramento River drainage*" (1998) that the required number of ATUs from the time of egg fertilization to fry emergence is 1550°F ATU (Armour 1991). Given the regional discrepancies in reported ATU requirements, and the lack of run-specific information on ATU requirements, the analysis in SP-F10 Task 2D assumed that 1,550 Fahrenheit ATUs (DFG 1998) are required from egg fertilization to fry emergence for Chinook salmon in the lower Feather River. The number of days required for egg incubation through fry emergence was calculated as the number of days until the sum of daily mean water temperatures (minus 32 ºF) met or exceeded 1,550. The accumulation of 1,550 Fahrenheit ATUs was applied to both the 2002/2003 and 2003/2004 spawning timing ranges for Chinook salmon to determine the length of egg incubation and to predict the timing of fry emergence.

4.2.4 Chinook salmon redd depth distribution

Stream flow is a principal regulator of Chinook salmon spawning habitat by determining the area covered with water, the depth over gravel beds, water velocity, and substrate profiles. Daily or annual changes in river flow can influence salmon spawning distribution and success by altering one or more of these variables. Chinook salmon spawning site selection is a synergistic function involving critical habitat and population features including water depth, water velocity, substrate characteristics, intra-gravel flow, and adult escapement characteristics (Healey 1991)..

Fluctuations in water releases and their influence on water velocities and intra-gravel flow can induce direct egg and alevin mortality, primarily through desiccation and oxygen starvation, and indirect mortality through reduced oxygen supply and toxicity due to reduced removal of waste metabolites of incubating embryos. Redds constructed in shallow water are most susceptible to dewatering, and corresponding direct and indirect mortality to incubating embryos. The SP-F10 Task 2D assessment of the potential effects of flow fluctuations on Chinook salmon embryonic incubation addressed the potential for redd dewatering to occur from project operations.

Chinook salmon have been observed spawning in water depths ranging from 0.16 feet to more than 20 feet (Healey 1991). Observed mean spawning depths, rather than ranges, are more consistently reported in the literature. Several studies reported mean spawning depths between one and two feet (Healey 1991).

Depth distribution of Chinook salmon redds constructed in the HFC of the lower Feather River was measured in 1991, and ranged from 0.55 to 3.3 feet (mean = 1.85 feet) in depth (Sommer et al. 2001). Because more recent Chinook salmon redd depth distribution data for the HFC are not available, the 1991 HFC redd depth distribution data were applied to the 2002/2003 study period (August 13, 2002 through February 24, 2003) and to the 2003/2004 study period (August 9, 2003 through March 13, 2004), for which detailed temporal and spatial spawning carcass data, and corresponding river flow and stage data, were available. For additional consideration and discussion of Chinook salmon redd depth distributions utilized for this analysis, see Section 6.1, *Existing Conditions/Environmental Settings*, of this report.

4.2.5 Temporal distribution of spawning activity

Calculation of the potential for Chinook salmon redd dewatering in the lower Feather River requires estimates of the daily spawning activity during the study period. One component of our evaluation is establishing the number of redds built per day in the lower Feather River. The number of days to egg hatching and alevin emergence (based on water temperature) determines the specific time period that each redd is vulnerable to dewatering due to river stage reductions. Ideally, daily redd surveys would establish when each individual redd is built. However, daily redd surveys are not feasible in the lower Feather River. Instead, weekly carcass surveys, generally covering approximately 40 pool/riffle complexes, are conducted during the spawning season.

Chinook salmon spawning has been reported to occur over a period of 5 to 14 days (Allen and Hassler 1986). Once spawning commences, the female will spend 4-25 days guarding her redd (Healey 1991). Life expectancy after spawning has been reported as 2 to 4 weeks (Briggs 1953). The duration of these events is likely water temperature-dependent, and may be shortened if spawning occurs at water temperatures above the adult's thermal preference. The duration of spawning activity also appears to be dependent on the arrival time of the spawning females, as early spawning females have been observed defending their redds longer than later arriving females (Neilson and Banford 1983). Given this information, one can reasonably assume that, in general, 2 to 4 weeks elapse between redd construction and carcass detection. A lag phase of three weeks between initiation of spawning (i.e., redd construction) and detection of adult carcasses was estimated for the lower American River, as a result of the analysis of four years of concurrent aerial redd and carcass survey data for fall-run Chinook salmon (SWRI, unpublished data). However, data from concurrent aerial redd and carcass surveys over several spawning seasons are not available for the lower Feather River. Therefore, for the purpose of this analysis, it was assumed that a three-week interval occurred between the initiation of spawning (redd construction) and the observation of the adult carcasses, based on the information derived from literature, and on the analysis of the lower American River data.

4.3 ANALYTICAL PROCEDURES

To assess the potential effects of Oroville Facilities operations on flow fluctuations and Chinook salmon redd dewatering in the HFC, several analytical steps were undertaken, as described below.

4.3.1 Estimate the number of redds constructed each day throughout the spawning season

4.3.1.1 2002 Spawning Season

The estimation of the number of Chinook salmon redds constructed each day throughout the spawning season included five components:

- The individual-day carcass counts in the HFC were corrected by the corresponding weekly proportion of spawned female carcasses identified during the 2002 carcass survey to obtain the individual-day counts of spawned female carcasses in the HFC.
- Individual-day counts of spawned female carcasses were summed over the carcass survey period to obtain a cumulative distribution.
- A Negative Exponential Value (NEV) curve was fitted to the observed cumulative distribution of spawned female carcasses to obtain the expected daily cumulative distribution of spawned female carcasses in the HFC.
- The estimated daily distribution of spawned female carcasses was calculated by subtracting previous-day cumulative values from current-day cumulative values provided from the fitted NEV curve.
- The estimated daily distribution of spawned female carcasses was lagged 3 weeks earlier to account for the time interval between spawning and observation in the carcass survey, and to represent the daily distribution of redd construction, assuming one redd per female.

The individual-day carcass counts observed in the HFC during the 2002 carcass survey (DWR, unpublished data) were corrected by the weekly proportions of spawned female carcasses to generate the individual day counts of spawned female carcasses in the HFC. The weekly proportions of spawned female carcasses (Table 4.3-1) were obtained from the weekly samples of female carcasses that were classified as “spawned” or “unspawned” based on the visual inspection of the number of eggs retained in their ovaries. The individual-day counts of female carcasses in the HFC were summed over the carcass survey period to obtain a cumulative distribution.

Table 4.3-1. Proportion of Chinook salmon spawned female carcasses in the HFC of the lower Feather River, 2002.

Week	Dates	Spawned	Un-spawned
1	9/3 - 9/5	0.0455	0.9545
2	9/9 - 9/12	0.0263	0.9737
3	9/16 - 9/19	0.0238	0.9762
4	9/23 - 9/26	0.0417	0.9583
5	9/30 - 10/4	0.2778	0.7222
6	10/7 - 10/10	0.5862	0.4138
7	10/14 - 10/17	0.5938	0.4063
8	10/21 - 10/25	0.7200	0.2800
9	10/28 - 10/31	0.7526	0.2474
10	11/4 - 11/7	0.8060	0.1940
11	11/11 - 11/14	0.8986	0.1014
12	11/18 - 11/21	0.8868	0.1132
13	11/25 - 11/27	0.8529	0.1471
14	12/2 - 12/5	0.8125	0.1875
15	12/9 - 12/11	0.8000	0.2000

A Negative Extreme Value (NEV) model (Figure 4.3-1) was fit to the cumulative distribution of spawned female Chinook salmon carcasses because, of several models with an equal number of parameters (e.g., logistic, Gompertz, NEV) examined, the NEV model provided the smallest mean square error between observed and predicted values. The formula for the NEV model was:

$$Y(\%)_i = \alpha\left[1-\exp\left(-\exp\left(\beta_o+\beta_1 X_i\right)\right)\right]$$

Where:

$Y(\%)_i$ = sum of all spawned carcasses counted until a particular sampling date “*i*” of the corresponding carcass survey, expressed as a percentage; and

X_i = a continuous variable that measures the sampling date “*i*” as the number of days counted from the start of the carcass survey.

The values of α, β_o and β_1 are parameter estimates that determine the shape of the NEV curve fitted to the cumulative distribution of spawned female Chinook salmon carcasses. NEV parameter α was set to 1 because we analyzed proportional data that summed to 1, fitted parameter β_0 was equal to –10.4409, and fitted parameter β_1 was equal to 0.0952.

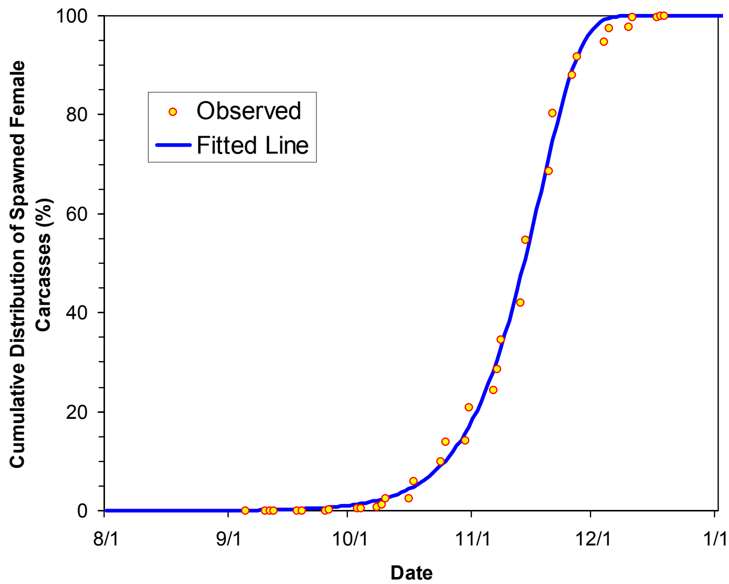

Figure 4.3-1. Cumulative distribution of spawned female Chinook salmon carcasses in the HFC of the lower Feather River, 2002.
Note: Circles indicate observed cumulative counts, and the line represents the Negative Extreme Value (NEV) curve fitted to the data.

The estimated daily distribution of spawned female carcasses (Figure 4.3-2) was calculated by subtracting previous-day cumulative values from current-day cumulative values provided by the fitted NEV line in Figure 4.3-1. Finally, based upon available literature and spawning timing analyses of fall-run Chinook salmon in the lower American River, the estimated daily distribution of spawned female carcasses was lagged 3 weeks earlier to account for the time interval between spawning and observation in the carcass survey, and to represent the daily distribution of redd construction (Figure 4.3-3), assuming one redd per female.

4.3.1.2 2003 Spawning Period

The estimated number of Chinook salmon redds constructed during the 2003 spawning season was calculated using the same methods as those utilized to estimate the number of redds constructed during the 2002 spawning season. Analyses were then conducted using the same methods described for analyses performed on data collected during the 2002 spawning period.

Estimates of individual-day carcass counts in the HFC in 2003 were corrected by the weekly proportions of spawned female carcasses to generate the individual day counts of spawned female carcasses in the HFC. Weekly counts of carcasses characterized as either “spawned” or “unspawned”, determined by visual inspection of the ovaries, were translated into weekly proportions of spawned female carcasses (Table 4.3-2). Using the same methods applied for the calculation of the cumulative distribution of spawned female carcasses in 2002, individual-day counts of female carcasses in the HFC were summed over the carcass survey period to obtain a cumulative distribution for the 2003 spawning period (Figure 4.3-4).

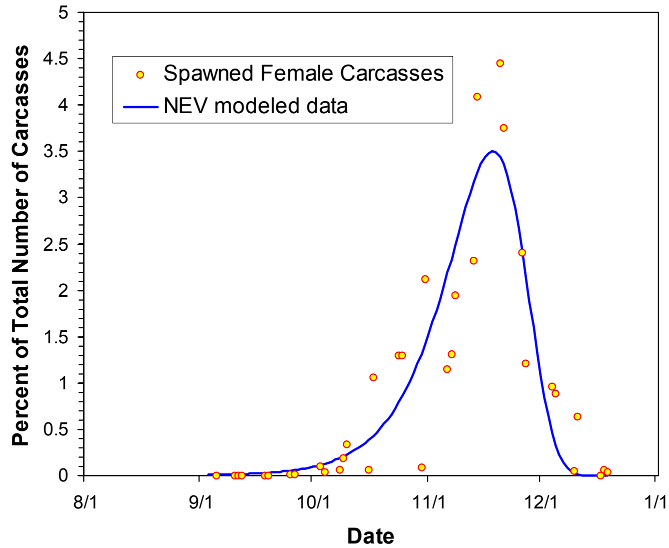

Figure 4.3-2. Daily distribution of spawned female Chinook salmon carcasses in the HFC of the lower Feather River, 2002.
Note: Circles indicate the daily percentage of the total number of spawned female Chinook salmon carcasses observed during the 2002 carcass survey. The line represents the Negative Extreme Value (NEV) curve fitted to the data.

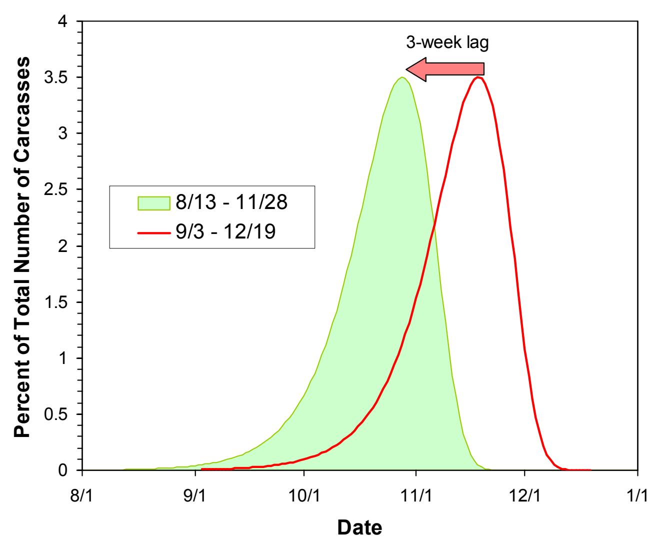

Figure 4.3-3. Daily distribution of spawned female Chinook salmon carcasses in the HFC of the lower Feather River, 2002.
Note: The red line represents the Negative Extreme Value (NEV) curve fitted to the daily percentage of the total number of spawned female Chinook salmon carcasses observed. The green-shaded area represents the daily distribution of redd construction corresponding to the fitted distribution of spawned female Chinook salmon carcasses.

Table 4.3-2. Proportion of Chinook salmon spawned female carcasses in the HFC of the lower Feather River, 2003.

Week	Dates	Spawned	Un-spawned
1	9/2 - 9/4	0.0000	1.0000
2	9/8 - 9/10	0.0000	1.0000
3	9/15 - 9/17	0.0000	1.0000
4	9/22 - 9/24	0.0000	1.0000
5	9/29 - 10/2	0.1143	0.8857
6	10/4 - 10/9	0.1471	0.8529
7	10/11 - 10/16	0.4054	0.5946
8	10/18 - 10/23	0.6610	0.3390
9	10/25 - 10/30	0.8254	0.1746
10	11/3 - 11/6	0.8476	0.1524
11	11/10 - 11/13	0.8986	0.1014
12	11/15 - 11/20	0.8876	0.1124
13	11/24 - 11/28	0.8590	0.1410
14	12/1 - 12/4	0.9262	0.0738
15	12/8 - 12/11	1.0000	0.0000
16	12/15 - 12/17	1.0000	0.0000

The Negative Extreme Value (NEV) model also was fit to the 2003 cumulative distribution using the identical model formula to that employed on the 2002 cumulative spawned female carcass distribution. The cumulative distribution of spawned female carcasses collected during the 2003 spawning season is shown in Figure 4.3-4. The values of α, β_o and β_1 are parameter estimates that determine the shape of the NEV curve fitted to the cumulative distribution of spawned female Chinook salmon carcasses. NEV parameter α was set to 1 because analyses were performed on proportional data that summed to 1, fitted parameter β_0 was equal to -10.4943, and fitted parameter β_1 was equal to 0.0877.

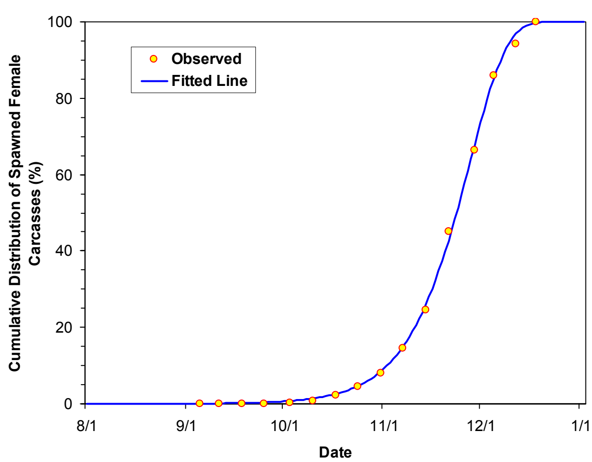

Figure 4.3-4. Cumulative distribution of spawned female Chinook salmon carcasses in the HFC of the lower Feather River, 2003.

The estimated daily distribution of spawned female carcasses, calculated by subtracting previous-day cumulative values from current-day cumulative values provided by the fitted NEV line (Figure 4.3-5), was lagged 3 weeks to account for the time interval between spawning and observation in the carcass survey (Figure 4.3-6). This method, described completely in the description of the 2002 carcass survey data analysis (section 4.3.1.1), is supported by both available literature and spawning timing analyses of fall-run Chinook salmon in the lower American River.

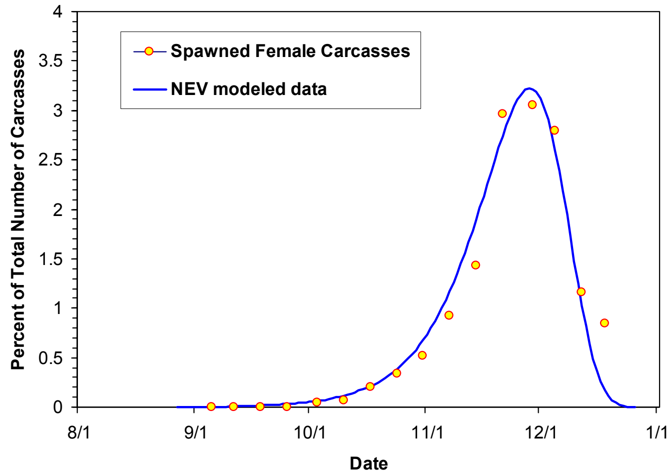

Figure 4.3-5. Daily distribution of spawned female Chinook salmon carcasses in the HFC of the lower Feather River, 2003.

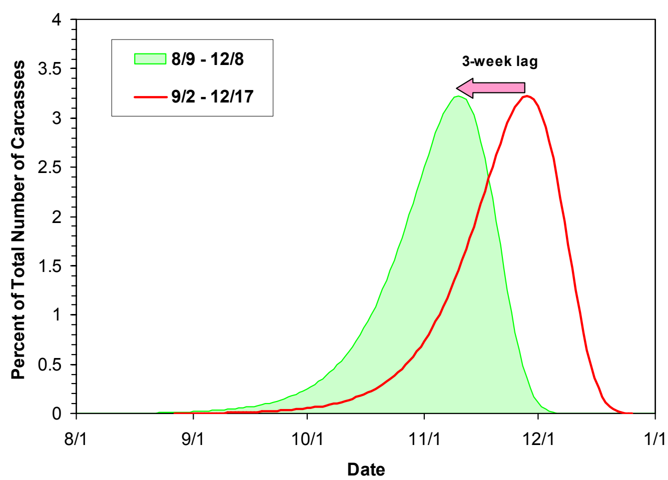

Figure 4.3-6. Daily distribution of spawned female Chinook salmon carcasses in the HFC of the lower Feather River, 2003.

4.3.2 Estimate the duration of individual redd incubation periods

4.3.2.1 2002/2003 individual redd incubation periods

Daily mean water temperatures were calculated by averaging hourly water temperatures measured by water temperature data loggers located at six locations along the HFC. Individual redd incubation periods were equal to the number of days required for egg incubation through fry emergence, expressed as the number of days until thermal units (mean daily water temperature (ºF) minus 32 ºF) met or exceeded an accumulated 1,550 ºF thermal units. The duration of incubation for each individual redd resulted in different potential days of exposure and, therefore, vulnerability to dewatering (Figure 4.3-7).

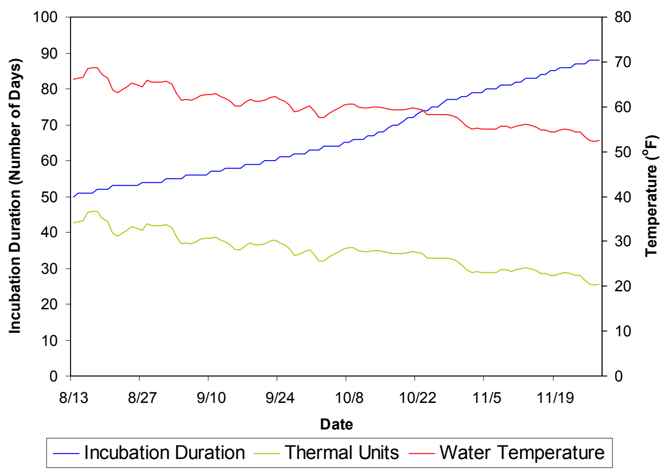

Figure 4.3-7. Average mean daily water temperature (ºF) in the HFC, daily thermal units, and the duration of incubation for individual redds constructed on the indicated dates during the estimated 2002 Chinook salmon spawning season (August 13 through November 28, 2002).

4.3.2.2 2003/2004 individual redd incubation periods

Daily mean water temperatures in the HFC were calculated for the 2003/2004 spawning and egg incubation period in the same manner as those calculated for the 2002/2003 spawning and egg incubation period. Individual redd incubation periods for the 2003/2004 spawning and egg incubation period also were determined by applying the same methods utilized to calculate the individual redd incubation periods during the 2002/2003 season. The duration of incubation for each individual redd resulted in differences in the number of days of potential exposure to dewatering events, and therefore, differences in vulnerability to dewatering (Figure 4.3-8).

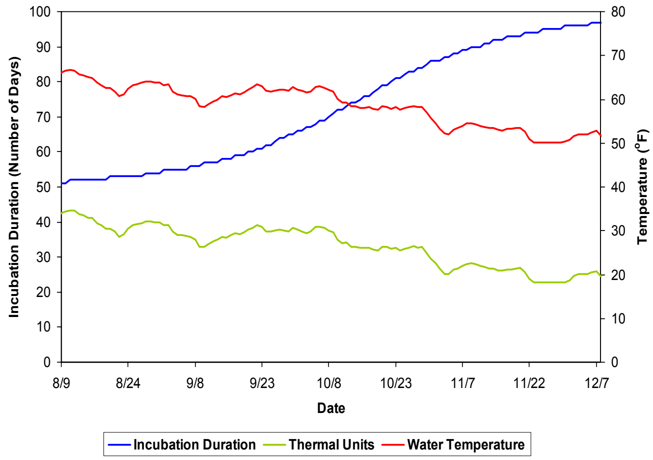

Figure 4.3-8. Average mean daily water temperature (ºF) in the HFC, daily thermal units, and the duration of incubation for individual redds constructed on the indicated dates during the estimated 2003 Chinook salmon spawning season (August 9, 2003 through December 7, 2003).

4.3.3 Estimate redd depth distribution

4.3.3.1 2002 redd depth distribution

The distribution of relative Chinook salmon redd depth frequencies (i.e., redd frequency at a particular depth / total number of redds) exhibited a nonlinear response (Figure 4.3-9). A polynomial regression, widely used in situations where the response is highly curvilinear, was chosen to obtain a smooth and continuous representation of the observed relative redd depth frequency. A fourth-order polynomial regression was fit to the data (r^2 =0.44, P = 0.03) resulting in the following equation:

$$Y = -0.30 + 0.90\,X - 0.74\,X^2 + 0.24\,X^3 - 0.03\,X^4$$

The resultant polynomial regression equation was then used to estimate the area under the curve for each depth interval, and the results were summed to obtain a cumulative redd depth distribution (Figure 4.3-10). The cumulative Chinook salmon redd depth distribution served as the basis against which river stage reductions were compared to estimate the percentage of redds dewatered during the 2002/2003 spawning and incubation season.

4.3.3.2 2003 redd depth distribution

The cumulative Chinook salmon redd depth distribution (Figure 4.3-10), based on 1991 data obtained by DWR, also was compared to the river stage reductions during the 2003/2004 spawning and incubation season to estimate the percentage of redds dewatered during the 2003/2004 season.

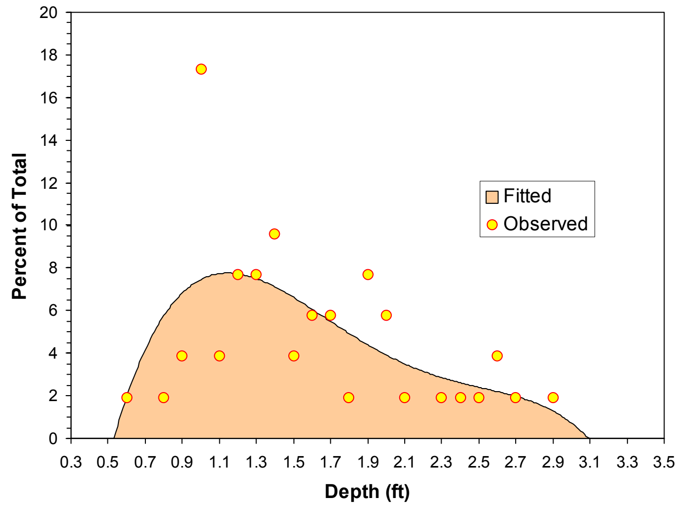

Figure 4.3-9. Chinook salmon redd depth distribution in the HFC of the lower Feather River, 1991 (DWR data).

Note: Circles indicate proportions (percent of total), and the line represents a polynomial curve fitted to the data (r^2 =0.44, P = 0.025).

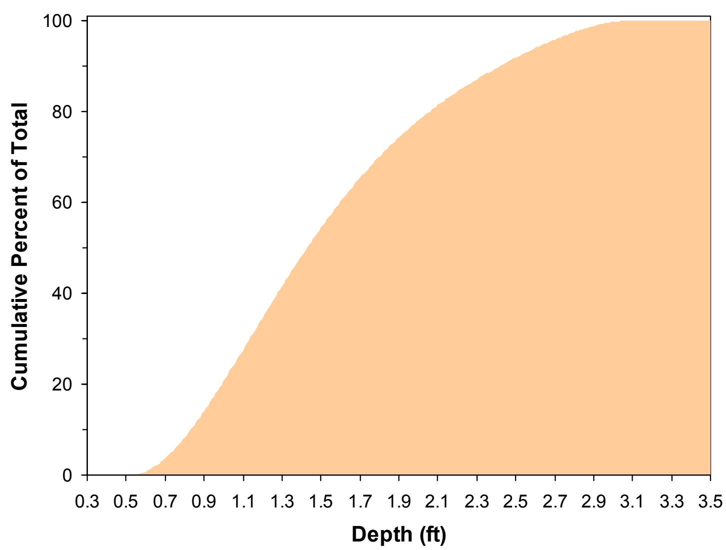

Figure 4.3-10. Chinook salmon redd depth cumulative distribution.

4.3.4 Calculate the maximum reduction in river stage that occurred during each individual redd incubation period

4.3.4.1. 2002/2003 maximum river stage reductions

To assess the potential effects of Oroville Facilities operations on flow fluctuations and Chinook salmon redd dewatering in the HFC of the lower Feather River, the river stage had to be calculated from flow data. Stage-discharge relationships were available for four riffles distributed throughout the HFC (TRPA, unpublished data). These relationships between stage and flow were used to generate the time series of daily stages of the four HFC riffles, and the daily average stage of the four. Figure 4.3-11 displays these stage-flow relationships that were modeled as power curves.

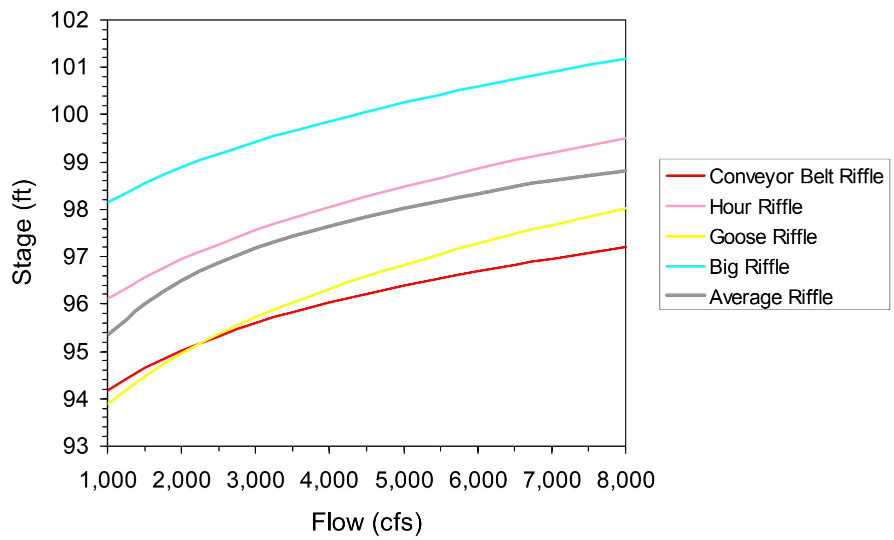

Figure 4.3-11. Stage-flow relationships for four riffles in the HFC of the lower Feather River used to convert daily mean flows into river stages.

Daily flows below the Thermalito Afterbay were obtained from California Data Exchange Center (California Data Exchange Center Website) and were input into the five stage-flow equations to generate the daily stages for the four riffles and the four-riffle average throughout the entire spawning and incubation season (Figure 4.3-12).

Maximum reductions in river stage were calculated for each individual redd incubation period (Figure 4.3-13). Maximum stage reductions were calculated using a macro written in Visual Basic, which considered daily river stage changes through time for each individual redd incubation period, and selected the largest reduction in stage.

4.3.4.2 2003/2004 maximum river stage reductions

Stage-flow relationships that were established during 2002 and were used to evaluate 2002/2003 flow data also are appropriate to analyze 2003/2004 flow data because of the similar channel morphology between the two years. It is assumed that because of the absence of major changes in the flow regime within the lower Feather River between 2002 and 2004, the morphology of river did not change enough to warrant further analysis of the stage-flow relationship. Therefore, the stage-flow relationship

(Figure 4.3-11) calculated from the 2002 data was applied to both the 2002/2003 and 2003/2004 flow data to determine the potential for dewatering events to occur.

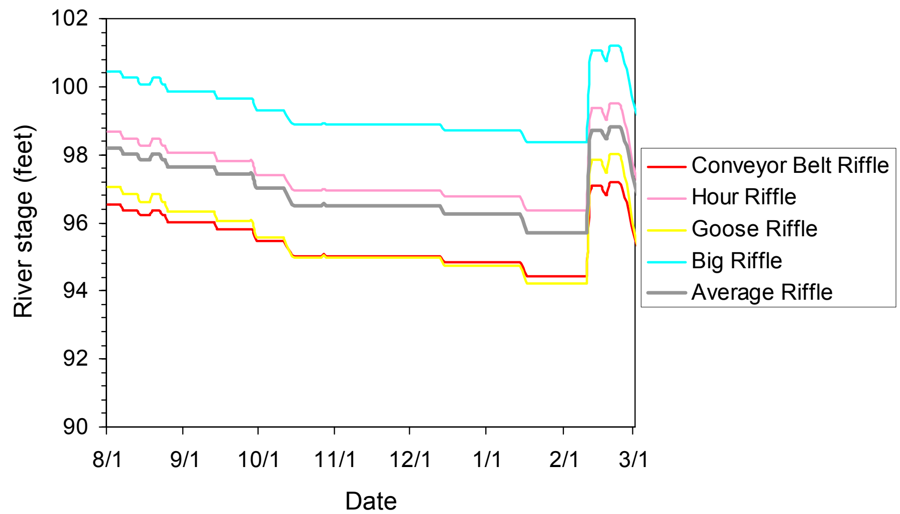

Figure 4.3-12. River stage (feet) at four riffles and the average of four riffles in the HFC of the lower Feather River, 2002/2003.

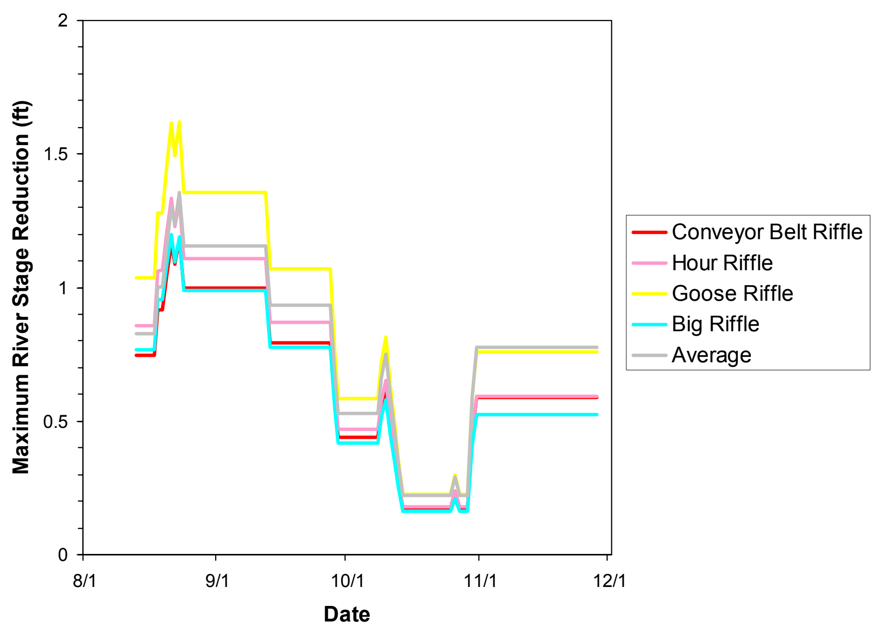

Figure 4.3-13. Maximum stage reductions that occurred during the incubation period corresponding to a redd constructed on the indicated date.

Streamflow data provided by DWR for the 2003/2004 Chinook salmon spawning and egg incubation season was used to calculate the river stage applying the same methodology used to calculate the river stage during the 2002/2003 Chinook salmon spawning and egg incubation season. Figure 4.3-11 provides a graphical representation of the stage-flow relationships used to provide a basis for analysis of flow reductions.

Daily flows below the Thermalito Afterbay Outlet were obtained from the California Data Exchange Center (CDEC) website in March 2004 (California Data Exchange Center Website). Flow data from the 2003/2004 Chinook salmon spawning and egg incubation period were input into the five stage-flow equations described in section 4.3.4.1 to determine the daily stages for each of the four riffles used in the analysis of the 2002/2003 spawning and egg incubation season, and to determine the four-riffle average stage (Figure 4.3-14).

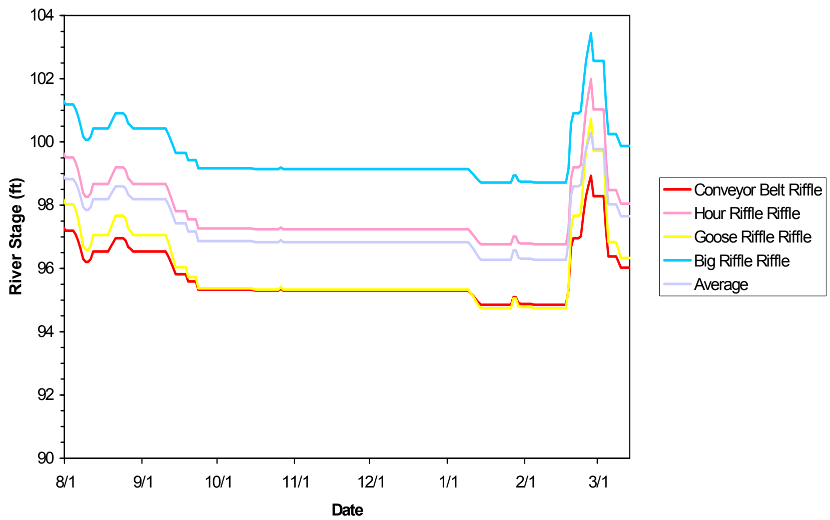

Figure 4.3-14. River stage (feet) at four riffles and the average of four riffles in the HFC of the lower Feather River, 2003/2004.

Maximum reductions in river stage were calculated for each individual redd incubation period during 2003/2004 using the same methodology that was utilized to calculate individual redd incubation periods during the 2002/2003 spawning and egg incubation season. Figure 4.3-15 shows the 2003/2004 maximum river stage reductions for each riffle, as well as the average stage reduction for all four riffles combined.

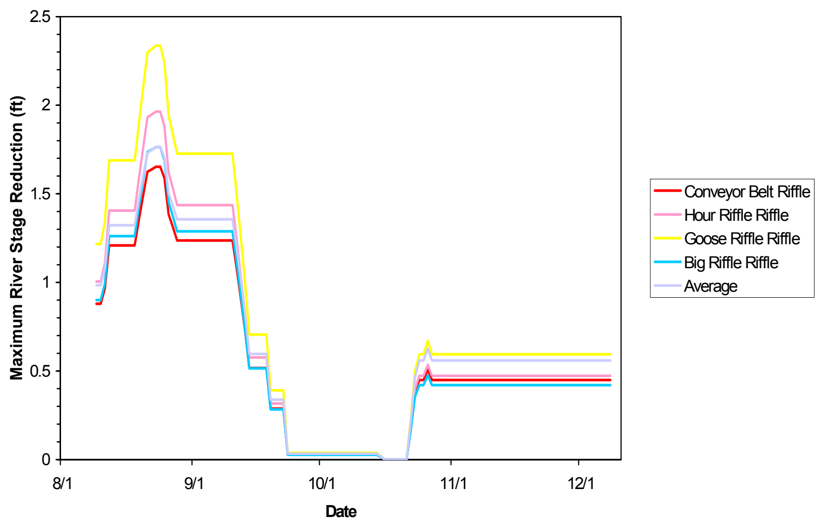

Figure 4.3-15. Maximum stage reductions that occurred during the incubation period corresponding to a redd constructed on the indicated date.

4.3.5 Calculate the percentage of the total number of redds dewatered in the HFC

4.3.5.1 2002/2003 Chinook salmon spawning and incubation period

The percentage of the total number of Chinook salmon redds that were dewatered in the HFC during the 2002/2003 spawning and incubation season was calculated by:

- From Figure 4.3-2, obtain the percentage of redds constructed a particular date of the estimated spawning season;
- From Figure 4.3-13, obtain the maximum river stage reduction that would have occurred throughout the incubation period for the redds constructed on a given date;
- From Figure 4.3-10, obtain the percentage of redds built at depths shallower than the maximum stage reduction obtained in previous step;
- Multiply the percentage of redds constructed on a particular date by the percentage of redds built at depths shallower than the maximum stage to obtain the daily percentage of constructed redds potentially subjected to dewatering throughout their specific incubation periods; and
- Repeat steps 1 through 4 for each date of the estimated spawning season, and sum the resulting daily percentages of dewatered redds to obtain the total percentage of redds dewatered in the HFC.

4.3.5.2 2003/2004 Chinook salmon spawning and incubation period

The percentage of the total number of Chinook salmon redds that were dewatered in the HFC during the 2003/2004 spawning and incubation season was calculated using the same methodology that was applied to the 2002/2003 data, the steps of which are outlined in section 4.3.5.1.

4.3.6 Estimate overall percentage of Chinook salmon redds dewatered in the entire lower Feather River

4.3.6.1 2002/2003 overall percentage

The last component of the analytical procedure consisted of applying the estimated percentage of Chinook salmon redds dewatered to the total number of redds constructed in the lower Feather River. The following steps were included in this analysis:

- Calculate Schaefer escapement estimates for the total Chinook salmon returning adult population for 2002 (Estimates obtained from SP-F10 Task 2B);
- Separate the 2002 total Chinook salmon population estimate into the number of adult fish in the Low Flow Channel (LFC) from those in the High Flow Channel (HFC) (Estimates obtained from SP-F10 Task 2B);
- Estimate the number of female adult Chinook salmon, relative to the estimated total number of adult Chinook salmon, by applying the estimated proportion of female carcasses to total carcasses identified to sex in the LFC and HFC during the 2002 carcass survey (DWR, unpublished data);
- Estimate the number of adult female Chinook salmon that actually spawned in the LFC and HFC by applying, to the results of Step 3 above, the estimated proportion of spawned female carcasses to total female carcasses categorized as “spawned” or “unspawned” during the 2002 carcass survey (DWR, unpublished data);
- Estimate the number of redds in the LFC and HFC by assuming 1 redd per spawned female.
- Estimate the percentage of redds dewatered in the LFC (assumed to be zero because of relatively constant flow of about 600 cfs during the spawning and incubation period); and
- Calculate the percentage of Chinook salmon redds dewatered in the entire lower Feather River by summing the estimated total number of redds dewatered in the LFC and HFC, divided by the estimated total number of redds constructed in the lower Feather River.

4.3.6.2 2003/2004 overall percentage

The same steps used to calculate the overall percentage of Chinook salmon redds dewatered in the lower Feather River during the 2002/2003 spawning and incubation season were followed using the data for the 2003/2004 Chinook salmon spawning and incubation season.

5.0 STUDY RESULTS

5.1 ESTIMATED MINIMUM DEPTH FOR CHINOOK SALMON REDDS CONSTRUCTED IN THE HFC

5.1.1 2002

Examination of the polynomial regression equation for the 1991 HFC Chinook salmon redd depth distribution indicates that, for the purposes of the SP-F10 Task 2D analysis, Chinook salmon redds were constructed at a minimum depth of 0.53 feet. Therefore, maximum stage reductions in the HFC of less than 0.53 feet during the 2002/2003 egg incubation through fry emergence period would not subject Chinook salmon redds to dewatering.

5.1.2 2003

Because the same data were used to calculate the Chinook salmon redd depth distribution for both spawning and egg incubation periods analyzed, for purposes of this analysis, Chinook salmon redds were constructed at a minimum depth of 0.53 feet in 2003. Therefore, maximum stage reductions in the HFC of less than 0.53 feet would not subject Chinook salmon redds to dewatering during the 2003/2004 egg incubation through fry emergence period.

5.2 ESTIMATED PERCENTAGE OF CHINOOK SALMON REDDS DEWATERED

To estimate the potential extent of Chinook salmon redd dewatering in the HFC, the SP-F10 Task 2D redd dewatering analysis was conducted utilizing stage-discharge relationships at four individual riffles in the HFC, for which recent (2002) stage-discharge data was collected (TRPA, unpublished data). Individual results were obtained using stage-discharge relationships from: (1) Big Riffle; (2) Conveyor Belt Riffle; (3) Hour Riffle; and (4) Goose Riffle. Examination of the stage-discharge relationship for each individual riffle was conducted to estimate the potential range (percent) of Chinook salmon redd dewatering during the 2002/2003 and 2003/2004 spawning and incubation periods in the HFC. Examination of the average stage-discharge relationship for all four riffles also was conducted to estimate the potential incidence (percent) of Chinook salmon redd dewatering. For the purposes of the SP-F10 Task 2D analysis, examination of each of these scenarios is assumed to encompass the range of maximum flow reductions to which Chinook salmon redds were estimated to be exposed to throughout the 2002/2003 and 2003/2004 egg incubation through fry emergence periods.

5.2.1 Average stage-discharge relationship for four riffles, 2002/2003

Using the average stage-discharge relationship for four riffles, a total of 3.1 percent of the Chinook salmon redds constructed in the HFC during the entire egg incubation through fry emergence period (August 13, 2002 through February 24, 2003) were estimated to be subjected to redd dewatering (Figure 5.2-1). Redds estimated to be constructed from August 13, 2002 through September 29, 2002, were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.68 to 1.36 feet (Figure 5.2-1). Approximately 1.13 percent of all Chinook salmon redds constructed in the HFC were estimated to be dewatered during this period. Redds estimated to be constructed from October 10, 2002 through October 12, 2002, and from October 31 through November 28, 2002, were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.59 to 0.75 feet and 0.59 to 0.78 feet, respectively (Figure 5.2-1). Approximately 0.13 and 1.84 percent, respectively, of all Chinook salmon redds constructed in the HFC were estimated to be dewatered during these periods. For the purposes of this analysis, Chinook salmon redds constructed during all other periods of time during the 2002 spawning season were not exposed to maximum stage discharges greater than the minimum redd construction depth of 0.53 feet and, thus, were not subjected to dewatering.

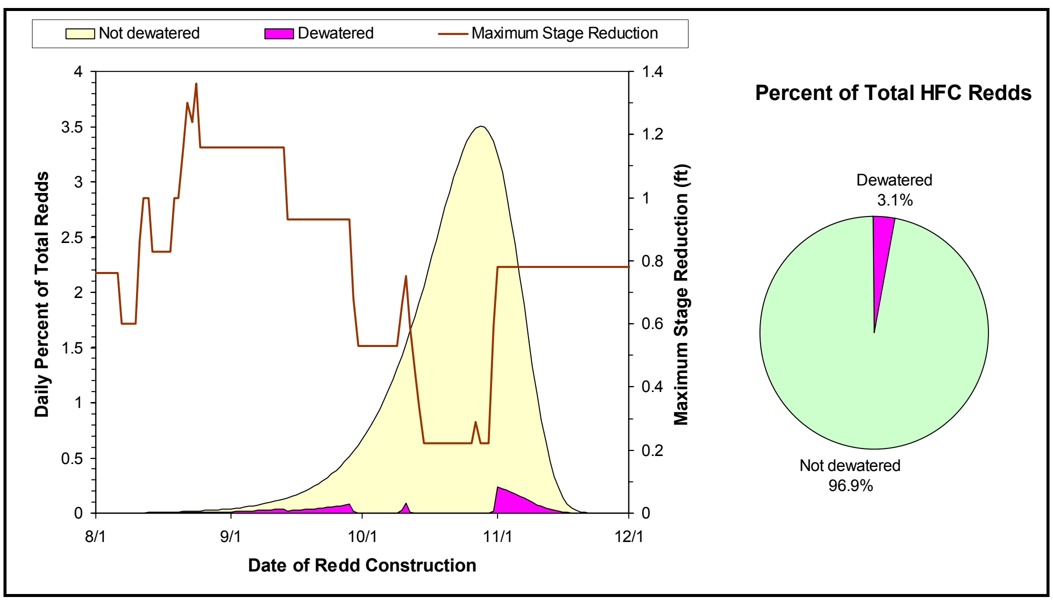

Figure 5.2-1. Estimated daily percent of total redds dewatered, and not dewatered, by maximum stage reductions that occurred during the 2002/2003 individual egg incubation through fry emergence periods, using the average stage-discharge relationship for four riffles in the HFC.

Figures 5.2-1 through 5.2-5 are, in part, graphical representations of: (1) the estimated dates of redd construction (X-axis); (2) the daily percent of total redds dewatered and not dewatered (left Y-axis); and (3) the maximum stage reduction (right Y-axis) that occurred during the individual incubation period of each redd constructed throughout the 2002 spawning period for each of the five stage-discharge relationships analyzed. For example, using the four-riffle average stage-discharge relationship (Figure 5.2-1), redds constructed on October 1, 2002, representing 0.6 percent of all redds constructed in the HFC, were exposed to an estimated maximum stage reduction of approximately 0.5 feet at some time during their corresponding incubation periods.

5.2.2 Big Riffle stage-discharge relationship

Using the stage-discharge relationship for Big Riffle, a total of 0.6 percent of the Chinook salmon redds constructed in the HFC during the entire egg incubation through fry emergence period (August 13, 2002 through February 24, 2003) were estimated to be subjected to redd dewatering (Figure 5.2-2).

Redds estimated to be constructed from August 13, 2002 through September 29, 2002, and on October 11, 2003, were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.54 to 1.2 feet and 0.58 feet, respectively (Figure 5.2-2). Approximately 0.59 and 0.01 percent, respectively, of all Chinook salmon redds constructed in the HFC were estimated to be dewatered during these periods. For the purposes of this analysis, Chinook salmon redds constructed during all other periods of time during the 2002 spawning season were not exposed to maximum stage discharges greater than the minimum redd construction depth of 0.53 feet and, thus, were not subjected to dewatering.

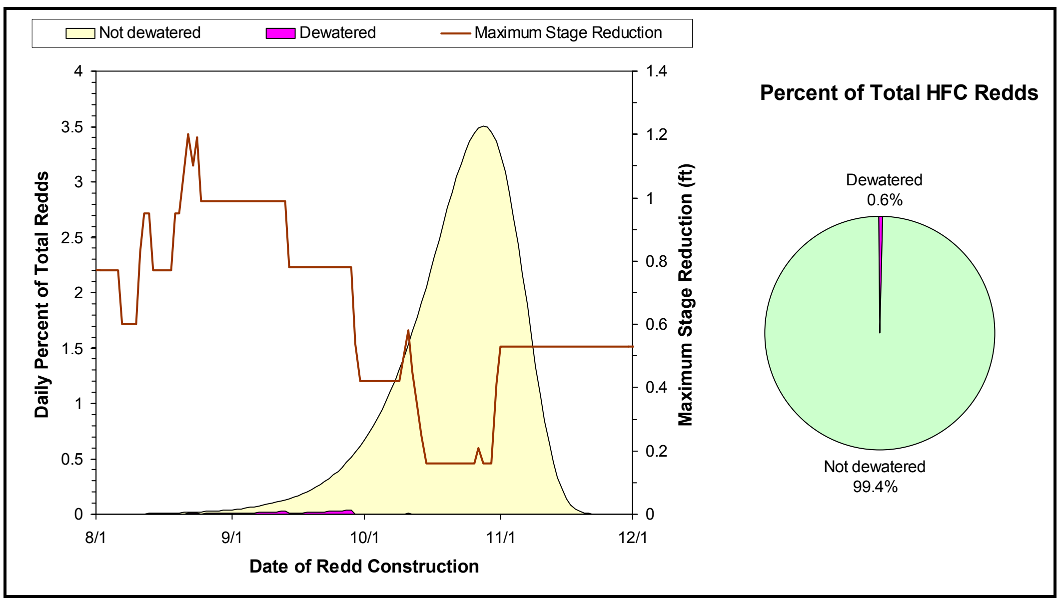

Figure 5.2-2. Estimated daily percent of total redds dewatered, and not dewatered, by maximum stage reductions that occurred during the 2002/2003 individual egg incubation through fry emergence periods, using the stage-discharge relationship for Big Riffle.

5.2.3 Conveyor Belt Riffle stage-discharge relationship

Using the stage-discharge relationship for Conveyor Belt Riffle, a total of 0.76 percent of the Chinook salmon redds constructed in the HFC during the entire egg incubation through fry emergence period (August 13, 2002 through February 24, 2003) were estimated to be subjected to redd dewatering (Figure 5.2-3).

Redds estimated to be constructed from August 13, 2002 through September 29, 2002, were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.74 to 1.18 feet (Figure 5.2-3). Approximately 0.61 percent of all Chinook salmon redds constructed in the HFC were estimated to be dewatered during this period. Redds estimated to be constructed on October 10, 2002 and October 11, 2002, and from November 1 through November 28, 2002, were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.54 to 0.61 feet and 0.59 feet, respectively (Figure 5.2-3). Approximately 0.01 and 0.14 percent, respectively, of all Chinook salmon redds constructed in the HFC were estimated to be dewatered during these periods. For the purposes of this analysis, Chinook salmon redds constructed during all other periods of time during the 2002 spawning season were not exposed to maximum stage discharges greater than the minimum redd construction depth of 0.53 feet and, thus, were not subjected to dewatering.

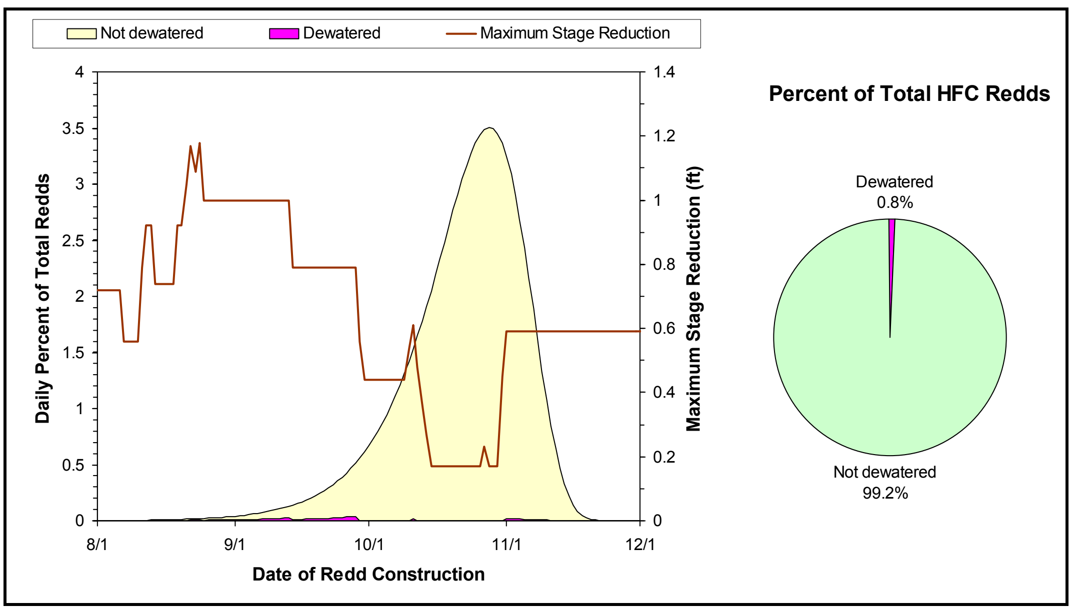

Figure 5.2-3. Estimated daily percent of total redds dewatered, and not dewatered, by maximum stage reductions that occurred during the 2002/2003 individual egg incubation through fry emergence periods, using the stage-discharge relationship for Conveyor Belt Riffle.

5.2.4 Hour Riffle stage-discharge relationship

Using the stage-discharge relationship for Hour Riffle, a total of 1.1 percent of the Chinook salmon redds constructed in the HFC during the entire egg incubation through fry emergence period (August 13, 2002 through February 24, 2003) were estimated to be subjected to redd dewatering (Figure 5.2-4).

Redds estimated to be constructed from August 13, 2002 through September 29, 2002, subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.61 to 1.34 feet (Figure 5.2-4). Approximately 0.92 percent of all Chinook salmon redds constructed in the HFC were estimated to be dewatered during this period. Redds estimated to be constructed on October 10, 2002 and October 11, 2002, and from November 1 through November 28, 2002, were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.58 to 0.65 feet and 0.59 feet, respectively (Figure 5.2-4). Approximately 0.04 and 0.14 percent, respectively, of all Chinook salmon redds constructed in the HFC were estimated to be dewatered during these periods. For the purposes of this analysis, Chinook salmon redds constructed during all other periods of time during the 2002 spawning season were not exposed to maximum stage discharges greater than the minimum redd construction depth of 0.53 feet and, thus, were not subjected to dewatering.

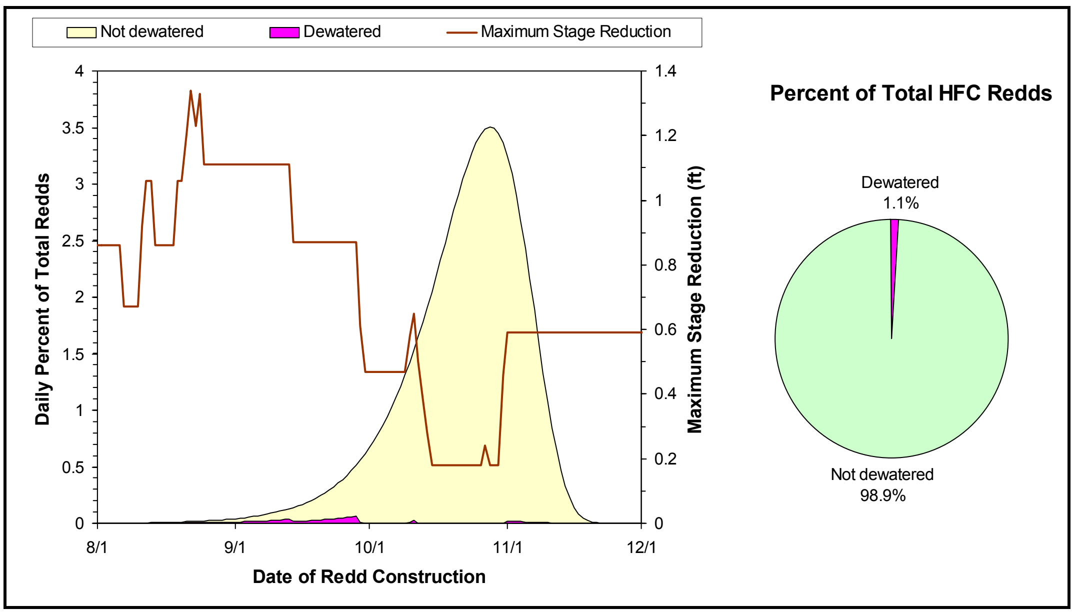

Figure 5.2-4. Estimated daily percent of total redds dewatered, and not dewatered, by maximum stage reductions that occurred during the 2002/2003 individual egg incubation through fry emergence periods, using the stage-discharge relationship for Hour Riffle.

5.2.5 Goose Riffle stage-discharge relationship

Using the stage-discharge relationship for Goose Riffle, a total of 3.6 percent of the Chinook salmon redds constructed in the HFC during the entire egg incubation through fry emergence period (August 13, 2002 through February 24, 2003) were estimated to be subjected to redd dewatering (Figure 5.2-5).

Redds estimated to be constructed from August 13, 2002 through October 12, 2002, and October 31, 2002 through November 28, 2002, were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.59 to 1.62 feet and 0.59 to 0.76 feet, respectively (Figure 5.2-5). Approximately 2.03 and 1.59 percent, respectively, of all Chinook salmon redds constructed in the HFC were estimated to be dewatered during these periods. For the purposes of this analysis, Chinook salmon redds constructed during all other periods of time during the 2002 spawning season were not exposed to maximum stage discharges greater than the minimum redd construction depth of 0.53 feet and, thus, were not subjected to dewatering.

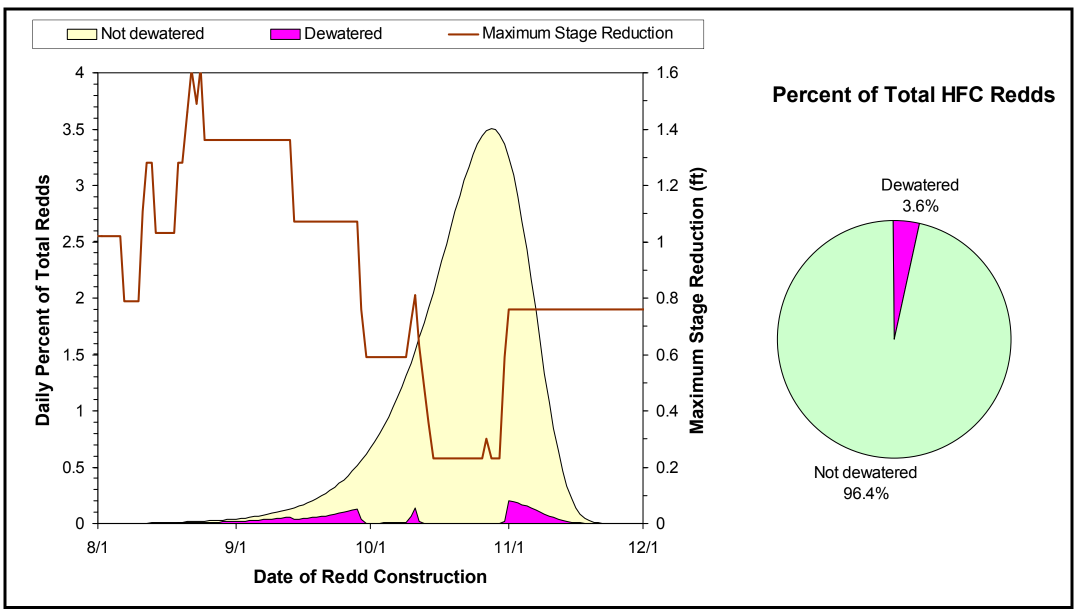

Figure 5.2-5. Estimated daily percent of total redds dewatered, and not dewatered, by maximum stage reductions that occurred during the 2002/2003 individual egg incubation through fry emergence periods, using the stage-discharge relationship for Goose Riffle.

5.2.6 Average stage-discharge relationship for four riffles, 2003/2004

Using the average stage-discharge relationship for four riffles, a total of 0.4 percent of the Chinook salmon redds constructed in the HFC during the entire egg incubation through fry emergence period (August 9, 2003 through March 13, 2004) were estimated to be subjected to redd dewatering (Figure 5.2-6).

Redds estimated to be constructed from August 9, 2003 through September 18, 2003, were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.60 to 1.76 feet (Figure 5.2-6). Approximately 0.24 percent of all Chinook salmon redds constructed in the HFC were estimated to be dewatered during this period. Redds estimated to be constructed from October 24, 2003 through December 4, 2003 were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.56 feet (Figure 5.2-6). Approximately 0.15 percent of all Chinook salmon redds constructed in the HFC were estimated to be dewatered during these periods. For the purposes of this analysis, Chinook salmon redds constructed during all other periods of time during the 2003 spawning season were not exposed to maximum stage reductions greater than the minimum redd construction depth of 0.53 feet and, thus, were not subjected to dewatering.

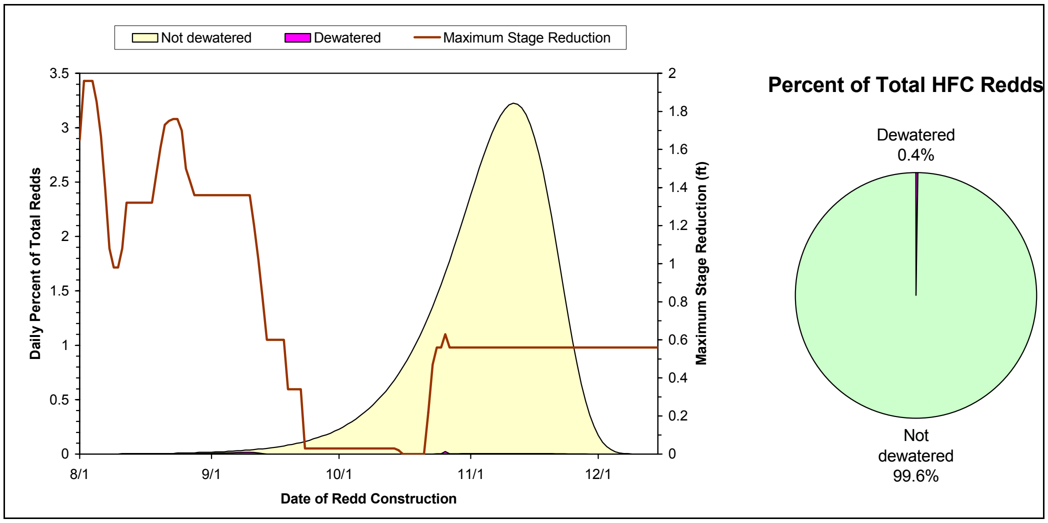

Figure 5.2-6. Estimated daily percent of total redds dewatered, and not dewatered, by maximum stage reductions that occurred during the 2003/2004 individual egg incubation through fry emergence periods, using the average stage-discharge relationship for four riffles in the HFC.

Figures 5.2-6 through 5.2-10 are, in part, graphical representations of: (1) the estimated dates of redd construction (X-axis); (2) the daily percent of total redds dewatered and not dewatered (left Y-axis); and (3) the maximum stage reduction (right Y-axis) that occurred during the individual incubation period of each redd constructed throughout the 2003 spawning period for each of the five stage-discharge relationships analyzed.

5.2.7 Big Riffle stage-discharge relationship

Using the stage-discharge relationship for Big Riffle, a total of 0.2 percent of the Chinook salmon redds constructed in the HFC during the entire egg incubation through fry emergence period (August 9, 2003 through March 13, 2004) were estimated to be subjected to potential redd dewatering events (Figure 5.2-7).

Redds estimated to be constructed from August 9, 2003 through September 13, 2003, were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.73 to 1.76 feet (Figure 5.2-7). Approximately 0.21 percent of all Chinook salmon redds constructed in the HFC were estimated to have been dewatered during these periods. For the purposes of this analysis, Chinook salmon redds constructed during all other periods of time during the 2003 spawning season were not exposed to maximum stage reductions greater than the minimum redd construction depth of 0.53 feet and, thus, were not subjected to dewatering.

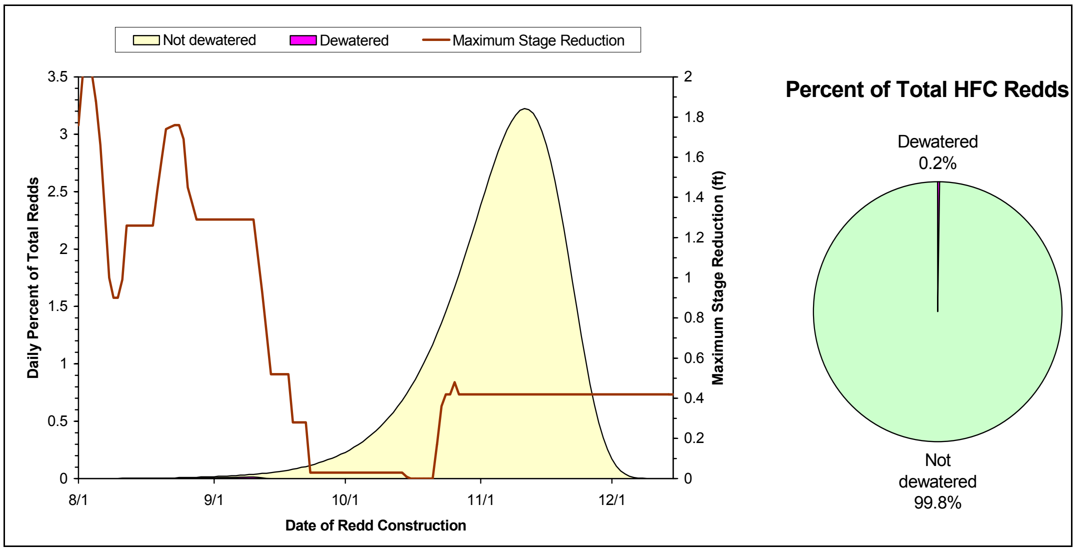

Figure 5.2-7. Estimated daily percent of total redds dewatered, and not dewatered, by maximum stage reductions that occurred during the 2003/2004 individual egg incubation through fry emergence periods, using the stage-discharge relationship for Big Riffle.

5.2.8 Conveyor Belt Riffle stage-discharge relationship

Using the stage-discharge relationship for Conveyor Belt Riffle, a total of 0.2 percent of the Chinook salmon redds constructed in the HFC during the entire egg incubation through fry emergence period (August 9, 2002 through March 13, 2004) were estimated to be subjected to redd dewatering (Figure 5.2-8).

Redds estimated to be constructed from August 9, 2003 through September 13, 2003, were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.58 to 1.96 feet (Figure 5.2-8). Approximately 0.19 percent of all Chinook salmon redds constructed in the HFC were estimated to have been dewatered during this period. For the purposes of this analysis, Chinook salmon redds constructed during all other periods of time during the 2003 spawning season were not exposed to maximum stage reductions greater than the minimum redd construction depth of 0.53 feet and, thus, were not subjected to dewatering.

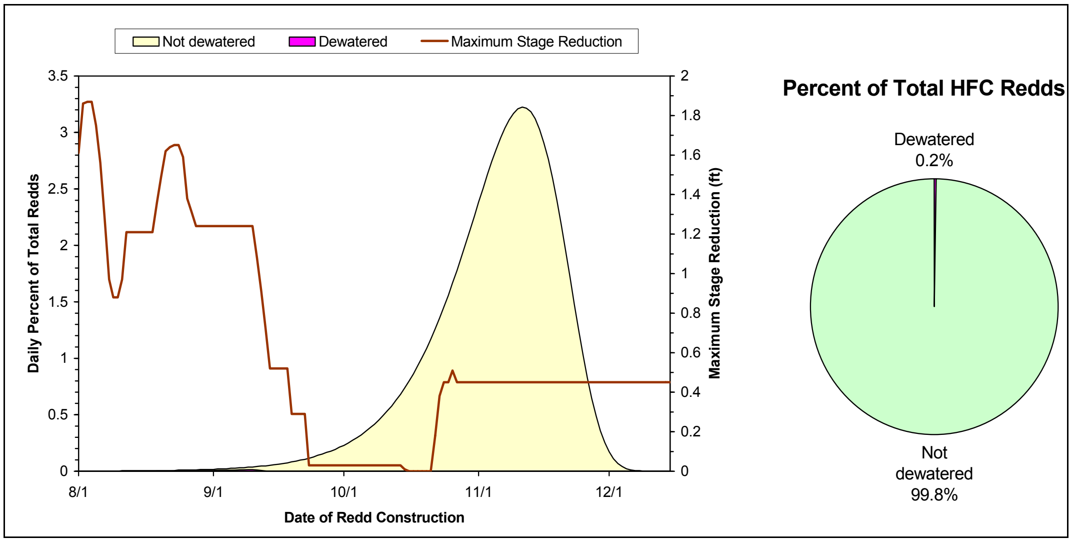

Figure 5.2-8. Estimated daily percent of total redds dewatered, and not dewatered, by maximum stage reductions that occurred during the 2003/2004 individual egg incubation through fry emergence periods, using the stage-discharge relationship for Conveyor Belt Riffle.

5.2.9 Hour Riffle stage-discharge relationship

Using the stage-discharge relationship for Hour Riffle, a total of 0.3 percent of the Chinook salmon redds constructed in the HFC during the entire egg incubation through fry emergence period (August 8, 2003 through March 13, 2004) were estimated to be subjected to redd dewatering (Figure 5.2-9). Redds estimated to be constructed from August 8, 2003 through September 18, 2003, were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.58 to 1.96 feet (Figure 5.2-9). Approximately 0.26 percent of all Chinook salmon redds constructed in the HFC were estimated to have been dewatered during this period. For the purposes of this analysis, Chinook salmon redds constructed during all other periods of time during the 2003 spawning season were not exposed to maximum stage reductions greater than the minimum redd construction depth of 0.53 feet and, thus, were not subjected to dewatering.

5.2.10 Goose Riffle stage-discharge relationship

Using the stage-discharge relationship for Goose Riffle, a total of 0.8 percent of the Chinook salmon redds constructed in the HFC during the entire egg incubation through fry emergence period (August 8, 2003 through March 13, 2004) were estimated to be subjected to redd dewatering (Figure 5.2-10).

Redds estimated to be constructed from August 8, 2003 through September 18, 2003, were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.71 to 2.34 feet (Figure 5.2-10). Approximately 0.36 percent of all Chinook salmon redds constructed in the HFC were estimated to have been dewatered during this period. Redds estimated to be constructed from October 24, 2003 through December 6, 2003, were subjected to a maximum stage reduction that occurred during their specific incubation periods of 0.59 to 0.67 feet (Figure 5.2-10). Approximately 0.48 percent of all Chinook salmon redds constructed in the HFC were estimated to have been dewatered during this period. For the purposes of this analysis, Chinook salmon redds constructed during all other periods of time during the 2003 spawning season were not exposed to maximum stage reductions greater than the minimum redd construction depth of 0.53 feet and, thus, were not subjected to dewatering.

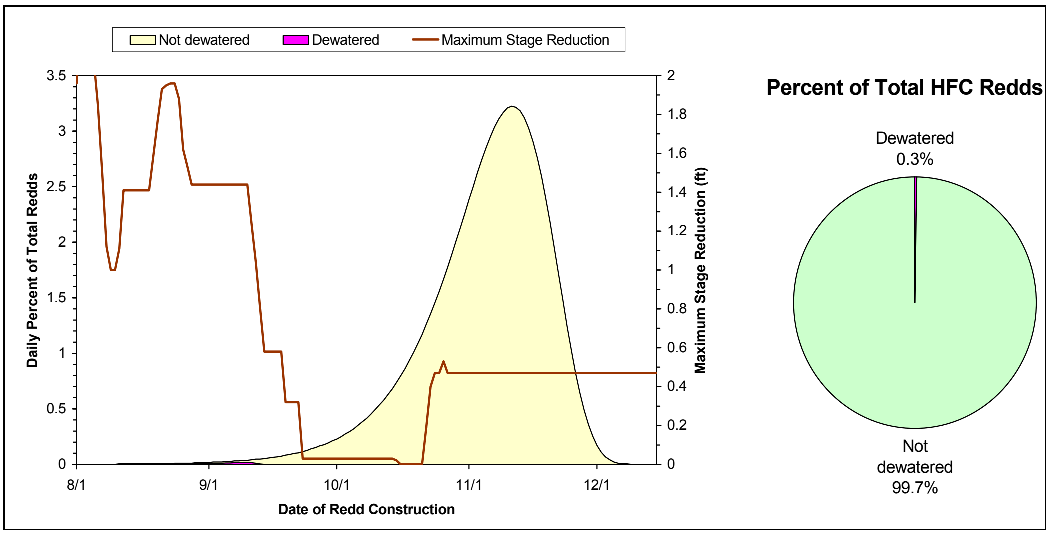

Figure 5.2-9. Estimated daily percent of total redds dewatered, and not dewatered, by maximum stage reductions that occurred during the 2003/2004 individual egg incubation through fry emergence periods, using the stage-discharge relationship for Hour Riffle.

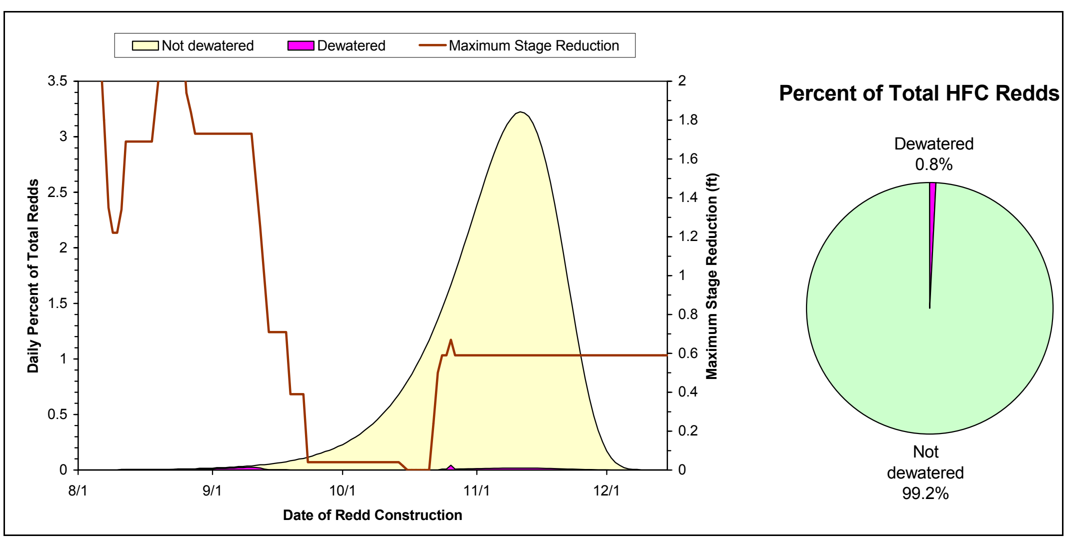

Figure 5.2-10. Estimated daily percent of total redds dewatered, and not dewatered, by maximum stage reductions that occurred during the 2003/2004 individual egg incubation through fry emergence periods, using the stage-discharge relationship for Goose Riffle.

5.3. ESTIMATED NUMBER OF CHINOOK SALMON REDDS CONSTRUCTED IN THE LOWER FEATHER RIVER IN 2002

Based on the Schaefer escapement estimates, and the estimated proportions of female carcasses and of spawned female carcasses obtained from the 2002 DWR carcass survey, an estimated 70,952 adult Chinook salmon reached the LFC during the 2002 spawning season (*SP-F10 Task 2B).* Of the estimated 70,952 adult Chinook salmon, 62.02 percent were females and 53.55 percent of those females had spawned. A total of 23,564 (i.e., 70,952 x $\frac{62.02}{100}$ x $\frac{53.55}{100}$ = 23,564) adult female Chinook salmon were estimated to have spawned in the LFC in 2002. Assuming one redd per female, an estimated minimum of 23,564 Chinook salmon redds were constructed in the LFC in 2002.

Similarly, an estimated 34,115 adult Chinook salmon reached the HFC during the 2002 spawning season. Of the estimated 34,115 adult Chinook salmon, 55.85 percent were females and 70.80 percent of those females had spawned. A total of 13,490 (i.e., 34,115 x $\frac{55.85}{100}$ x $\frac{70.80}{100}$ = 13,490) adult female Chinook salmon were estimated to have spawned in the HFC in 2002. Assuming one redd per female, an estimated minimum of 13,490 Chinook salmon redds were constructed in the HFC in 2002.

Consequently, of the estimated 37,054 (23,564 LFC + 13,490 HFC) Chinook salmon redds constructed in the lower Feather River in 2002, approximately 63.6 percent were constructed in the LFC and 36.4 percent were constructed in the HFC.

Because flows in the LFC were relatively constant (approximately 600 cfs) during the 2002/2003 Chinook salmon spawning and incubation period, no redds would have been expected to have been dewatered in the LFC. The analysis for SP-F10 Task 2D (Section 5.2.1) indicates that, on average, an estimated 3.1 percent of Chinook salmon redds were dewatered during the 2002/2003 spawning and incubation periods in the HFC (Figure 5.2-1). Consequently, it was estimated that 1.1 percent (i.e., $\left(\frac{63.6}{100}\times 0\right)+\left(\frac{36.4}{100}\times\frac{3.11}{100}\right)\times 100 = 1.1\%$) of all Chinook salmon redds constructed in the lower Feather River would have been subjected to dewatering during the 2002/2003 spawning and incubation season.

5.4 ESTIMATED NUMBER OF CHINOOK SALMON REDDS CONSTRUCTED IN THE LOWER FEATHER RIVER IN 2003

Based on Schaefer escapement estimates derived from carcass survey data collected in 2003, it is estimated that 58,468 adult Chinook salmon reached the LFC during the 2003 spawning season (DWR 2004). Of these, 67.09 percent were females and 53.76

percent of those females had spawned. Therefore, a total of 21,088 $\left(\text{i.e.,} 58,468 \times \frac{67.09}{100} \times \frac{53.76}{100} = 21,088\right)$ female Chinook salmon were estimated to have spawned in the LFC in 2003. Assuming one redd per female, an estimated minimum of 21,088 Chinook salmon redds were constructed in the LFC in 2003.

Similarly, it was estimated that 39,600 adult Chinook salmon reached the HFC during the 2003 spawning season. Of these, 64.51 percent were females and 61.16 percent of those females had spawned. A total of 15,624 females $\left(\text{i.e.,} 39,600 \times \frac{64.51}{100} \times \frac{61.16}{100} = 15,624\right)$ were estimated to have spawned in the HFC. Assuming one redd per female, an estimated minimum of 15,624 Chinook salmon redds were constructed in the HFC in 2003.

The estimated total number of Chinook salmon redds constructed in the lower Feather River in 2003 was 36,712 (21,088 LFC + 15,624 HFC). Approximately 57.4 percent of the redds were constructed in the LFC and 42.6 percent were constructed in the HFC.

Flows in the LFC remained relatively constant (at about 600 cfs) during the entire 2003/2004 Chinook salmon spawning and egg incubation period. Therefore, no Chinook salmon redds would be expected to be dewatered in the LFC. The analysis (Section 5.2.1) indicates that, on average, an estimated 0.4 percent of Chinook salmon redds were subject to dewatering events during the 2003/2004 spawning and egg incubation periods in the HFC (Figure 5.2-1). Consequently, it was estimated that 0.2 percent $\left(\text{i.e.,} \left(\frac{57.4}{100} \times 0\right) + \left(\frac{42.6}{100} \times \frac{0.4}{100}\right) \times 100 = 0.2\%\right)$ of all Chinook salmon redds constructed in the lower Feather River would have been subjected to dewatering during the 2003/2004 Chinook salmon spawning and incubation season.

5.4.1 Comparison of number of redds constructed in the lower Feather River in 2002 versus 2003

In 2002, 23,564 redds were estimated to have been constructed in the LFC, while in 2003, an estimated 21,088 redds were constructed in the LFC. In 2002, 13,490 redds were estimated to have been constructed in the HFC, while in 2003, 15,624 redds were estimated to have been constructed in the HFC. The total number of redds constructed did not vary substantially, however, the distribution of redd sites did differ between the two Chinook salmon spawning and incubation periods. About 11 percent fewer redds were constructed in the LFC in 2003 than were constructed in 2002. Similarly, about 14 percent more redds were estimated to be constructed in the HFC in 2003 than were constructed in 2002.

5.4.2 Comparison of redd dewatering events in the lower Feather River in 2002/2003 versus 2003/2004

A larger percentage of Chinook salmon redds were subject to dewatering during the 2002/2003 spawning and egg incubation season than during the 2003/2004 spawning and egg incubation season. In 2002, a total of 3.1 percent of the Chinook salmon redds constructed in the HFC during the entire egg incubation through fry emergence period (August 13, 2002 through February 24, 2003) were estimated to be subjected to potential redd dewatering events. In 2003, a total of 0.4 percent of the Chinook salmon redds constructed in the HFC during the entire egg incubation through fry emergence period (August 9, 2003 through March 13, 2004) were estimated to be subjected to potential redd dewatering events.

Although the 2002/2003 Chinook salmon spawning and incubation season was estimated to be shorter than the 2003/2004 season, there were more redds potentially subject to dewatering events in HFC during the 2002/2003 spawning and egg incubation period. Maximum river stage reductions were greater during the 2002/2003 Chinook salmon spawning and egg incubation season than during the 2003/2004 Chinook salmon spawning and incubation season.

Because flows in the LFC were relatively constant (approximately 600 cfs) during both the 2002/2003 and 2003/2004 Chinook salmon spawning and egg incubation seasons, no redds were expected to have been dewatered in the LFC during either of the spawning and egg incubation seasons.

The potential for Chinook salmon redd dewatering in the entire lower Feather River was therefore higher during the 2002/2003 spawning and incubation season than it was during the 2003/2004 spawning and incubation season. During the 2002/2003 season, the total number of Chinook salmon redds constructed in the lower Feather River subject to dewatering was 1.1 percent, while during the 2003/2004 season, a total of 0.2 percent of all Chinook salmon redds constructed in the lower Feather River were subjected to dewatering (Table 5.4-1).

Table 5.4-1. Estimation of the percentage of redds potentially dewatered during the 2002/2003 and 2003/2004 spawning and egg incubation seasons based on the respective average four-riffle maximum river stage reductions.

River Reach	Percentage of redds potentially dewatered during the 2002/2003 spawning and incubation season	Percentage of redds potentially dewatered during the 2003/2004 spawning and incubation season
HFC	3.1 %	0.4 %
LFC*	0%	0%
Entire lower Feather River	1.1%	0.2%

** Due to relatively constant flows observed in the LFC (approximately 600 cfs) during both the 2002/2003 and 2003/2004 Chinook salmon spawning and incubation seasons, no redds would have been expected to have been dewatered in the LFC.*

6.0 ANALYSES

6.1 EXISTING CONDITIONS/ENVIRONMENTAL SETTING

Task 2D is a subtask of SP-F10, *Evaluation of Project Effects on Salmonids and their Habitat in the Feather River Below the Fish Barrier Dam.* Task 2D fulfills a portion of the FERC application requirements by evaluating the potential for, and the impact from, the dewatering of Chinook salmon redds due to flow fluctuations in the lower Feather River.

6.1.1. Other studies and data sets

During the 2002/2003 Chinook salmon spawning season, DWR conducted Chinook salmon redd dewatering studies in the lower Feather River. During this period, major spawning riffles in the HFC were visited after each reduction in flow. Measurements included river mile, flow and the number of exposed redds. The incidence of redd dewatering was compared with the estimated number of salmon redds from the 2002 spawning season to determine redd losses as a proportion of the total number of redds in the river.

The redd dewatering surveys were conducted in the HFC of the lower Feather River, extending from the Thermalito Afterbay Outlet (RM 59) to the confluence with Honcut Creek. Under normal operations, this area has the highest potential for redd dewatering to occur, and was therefore the focus of the redd dewatering investigations.

DWR concluded that a very small percentage of Chinook salmon redds were dewatered during the 2002/2003 spawning and incubation period, and that project operations during that period did not appear to have a significant impact on salmon egg production in the lower Feather River (DWR 2003).

This analysis, conducted for SP-F10 Task 2D, was based on the redd depth distribution obtained from Chinook salmon redds measured in the HFC in 1991. Low flows occurred in the lower Feather River in 1991, with flows of approximately 600 cfs in the LFC and approximately 1,000 cfs in the HFC. Concerns regarding potential bias introduced to the redd depth distribution under these conditions led DWR to conduct a controlled flow survey and re-examination of Chinook salmon redd depth distribution in 1995. In 1995, flows during the controlled flow Chinook salmon redd surveys were approximately 1,600 cfs in the LFC, and approximately 2,500 cfs in the HFC. During the 1995 controlled flow survey, Chinook salmon redd depths were only measured in the LFC. Recently, all redd depth data from the 1991 LFC and HFC surveys, and the 1995 LFC survey, were combined and the resultant Chinook salmon redd depth distribution was utilized in re-examination of flow-habitat relationships in the lower Feather River (*SP-F16, Evaluation of Project Effects on Instream Flows and Fish Habitat, Phase 2 Draft Final Report*).

To examine whether utilization of the 1991 HFC data alone potentially influenced results of the SP-F10 Task 2D analysis, we compared the 1991 HFC redd depth distribution data set to a combined data set that included the 1991 LFC, 1991 HFC and 1995 LFC Chinook salmon redd depth measurements. Similar to the methodology described in Section 4.3.3 of this report, a polynomial regression equation was fit to the combined data ($r^2 = 0.89$, $P < 0.01$). The Chinook salmon redd depth frequency distributions for each data set (1991 HFC only, and 1991 LFC, 1991 HFC and 1995 LFC combined) and their corresponding polynomial regression equations were compared (Figure 6.1-1).

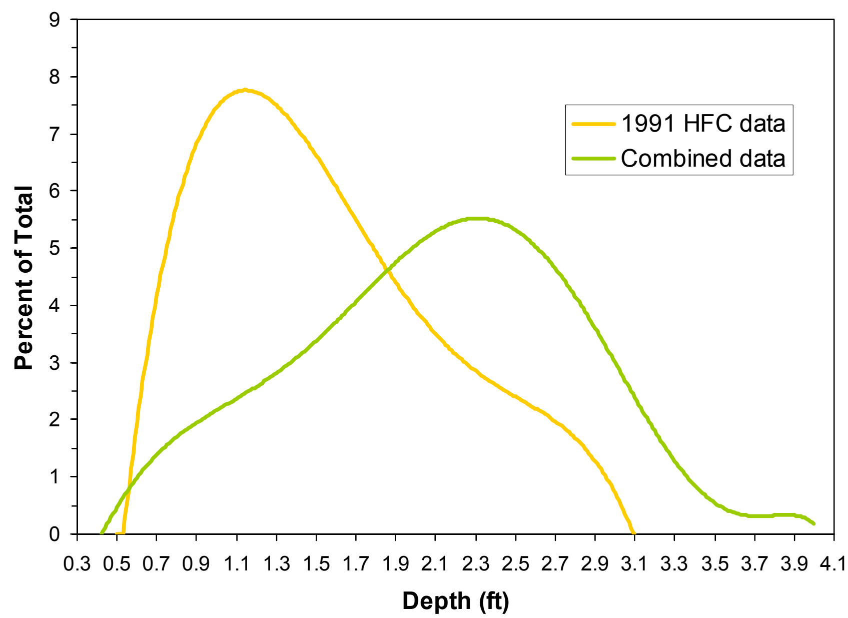

Figure 6.1-1. Comparison of polynomial regression equations representing Chinook salmon redd depth frequency distributions for two distinct data sets – the 1991 HFC data only (r^2 = 0.44, P = 0.03), and the 1991 LFC, 1991 HFC and 1995 LFC combined data set (r^2 = 0.89, P < 0.01).

Comparison of these two distributions indicate that the 1991 HFC Chinook salmon redd depth frequency distribution exhibits a substantially higher percentage of redds in shallower water than the combined data set. The 1991 HFC Chinook salmon redd depth frequency distribution exhibits a modal depth approximately 50 percent shallower, a median depth approximately 33 percent shallower and an estimated maximum depth approximately 25 percent shallower than the combined data set.

Utilization of the 1991 HFC data alone would indicate a higher incidence of potential dewatering of Chinook salmon redds than would be indicated utilizing the 1991 and 1995 combined data set. Therefore, utilization of the 1991 HFC data alone in the analysis for SP-F10 Task 2D, is more conservative, and represents a more rigorous approach to the identification of the potential incidence of Chinook salmon redd dewatering in the lower Feather River.

6.2 PROJECT-RELATED EFFECTS

6.2.1 2002/2003

The incidence of redd dewatering was compared with the estimated total number of Chinook salmon redds from the 2002 spawning season in the lower Feather River. In the lower Feather River, the highest percentage of Chinook salmon spawn in the LFC (Sommer et al. 2001). In 2002, an estimated 23,564 (63.6 percent of the total) Chinook salmon redds were constructed in the LFC, whereas 13,490 (36.4 percent of the total) Chinook salmon redds were constructed in the HFC of the lower Feather River.

Project operations apparently do not result in Chinook salmon redd dewatering in the LFC, within which an estimated 63.6 percent of all lower Feather River Chinook salmon redds were constructed in 2002, due to the relatively constant flows (approximately 600 cfs) that occur during the spawning and incubation periods. In the HFC, an average estimate of 3.1 percent of Chinook salmon redds were subjected to dewatering during the 2002/2003 spawning and incubation period, within which an estimated 36.4 percent of all lower Feather River Chinook salmon redds were constructed in 2002.

Therefore, an estimated 1.1 percent of all Chinook salmon redds constructed in the lower Feather River would have been subjected to dewatering during the 2002/2003 spawning and incubation season.

6.2.2 2003/2004

The estimated total number of Chinook salmon redds from the 2003 spawning season was compared with the incidence of potential redd dewatering events in the lower Feather River. An estimated 21,088 Chinook salmon redds were constructed in the LFC of the Feather River, whereas 15,624 Chinook salmon redds were estimated to have been constructed in the HFC in 2003.

Due to the relatively constant flows of approximately 600 cfs that occur during the spawning and egg incubation periods for Chinook salmon, project operations apparently do not result in Chinook salmon redd dewatering in the LFC, within which an estimated 57.4 percent of all Chinook salmon redds were constructed in 2003. The HFC contained an estimated 42.6 percent of the Chinook salmon redds constructed in the lower Feather River during the 2003 spawning season. In the HFC, an average estimate of 0.4 percent of Chinook salmon redds were subjected to potential dewatering events during the 2003/2004 Chinook salmon spawning and egg incubation season. Therefore, an estimated 0.2 percent of all Chinook salmon redds constructed in the lower Feather River would have been subjected to potential dewatering events during the 2003/2004 spawning and incubation season.

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